MAP DESIGN FOR PARTIALLY SEEING STUDENTS; AN INVESTIGATION OF WHITE VERSUS BLACK LINE SYMBOLOGY

BY

GERALD LEE GREENBERG

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Abstract

MAP DESIGN FOR PARTIALLY SEEING STUDENTS; AN INVESTIGATION OF WHITE VERSUS BLACK LINE SYMBOLOGY

by Gerald Lee Greenberg

Chairman of Supervisory Committee: Professor John C. Sherman
Department of Geography

Improved map and graphic aids are urgently needed to facilitate education of persons having severe visual impairments (partial sight). There has already been some experimental development and production of large-print textbooks used in sight-saving classes attended by these persons, but there is a definite paucity of map and graphic research.

This study is the first known systematic investigation of elements of map design for partially seeing students. A hypothesis is proposed that, for some groups of partially seeing students: (A) maps with white line symbology on black or dark gray backgrounds are more readable at greater viewing distances than are maps with identical black line symbology printed on a white background; (B) a certain range of line-widths of white symbols drawn on dark backgrounds can be seen further and are more readable than equivalent line-widths of black symbols on light backgrounds; and (C) line-widths for white symbols on dark backgrounds may be thinner than line-widths for black symbols on light backgrounds. The effect of irradiation, the basis for the hypothesis, is expressed in the visual illusion where black images appear narrower on a white background and white images appear wider on a black background. A number of special map design characteristics (line-width, viewing distance, and symbol-to-background relationships) relating to this hypothesis were investigated, and their effects upon map readability were experimentally verified. This was achieved through

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creation of a unique, new system of procedures for simultaneously testing and subsequently analyzing alternate combinations of map design elements.

Extensive basic research on perceptual requirements of persons with highly restricted vision was carried out during the preliminary phase of this work. As a result of widespread correspondence, personal observations and library investigations, much information containing specifications for large-print educational materials was collected and analyzed in order to select the map design characteristics to be evaluated.

A psychophysical research method was employed in this study in experimental cartography. Subject reading response trend effects from a systematically designed map test were measured under prescribed conditions of environment and subject control. The map test provided a means of measuring the accuracy with which subjects could perform an assigned reading task utilizing map test samples which were of uniform geographic area coverage, but varied in their individual visual characteristics. The major visual differences between the various test maps designed and employed, were the line-width of symbols and the symbol-to-background contrast relationships. The subject's performance of an assigned task (counting of a specially selected symbol on all test maps) is the principal response data utilized for judging the relative readability and design effectiveness of the different maps employed in the map test.

Assembly and production of the map test was accomplished through a specially developed photomechanical system of procedures which included processes of precision scribing, multiple-exposure photography, tonal screening and Ozalid reproduction. These procedures, along with an explanation and description of the structure of the map test are included. An Appendix listing equipment and materials is also provided.

Forty-three partially seeing student subjects were tested in this experiment, and a statistical analysis of their map test responses, using rank-order and special graphic mean trend methods, was carried out. In addition, a difference-of-means test and regression analysis of the mean test scores was performed in order to check the findings of the methods initially utilized. All of these methods indicated a positive confirmation of the hypothesis.

Within the content of this work are also included special illustrations, design matrices, complete map test response data tables, special trend analysis graphic tables, a comprehensive bibliography, and a sample map test (37 plates) including subject instructions and viewing distance control devices (Appendix, Volume 2).

UNIVERSITY OF WASHINGTON

Date: July 16, 1968

We have carefully read the dissertation entitled Map Design for Partially Seeing Students; An Investigation of White Versus Black Line Symbology

submitted by

Gerald L. Greenberg in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the dissertation.

The production of improved maps and other graphic aids for partially seeing children must be based upon precise knowledge of the relationship between their visual abilities (acuity) and symbol characteristics which might be incorporated into maps and graphics. This knowledge is fundamental in developing principles of effective cartographic design which could be employed in creating such maps. In this study, Mr. Gerald Greenberg has provided a unique summary and analysis of literature on this subject together with an experimental test designed to provide data and conclusions which can be applied in the development of maps and graphics for the partially seeing. The hypothesis which is tested and proven by the test data and Mr. Greenberg's analyses of them, when applied, holds forth possibilities which can profoundly influence all types of visual aids for the partially seeing.

To our knowledge, this study is the only comprehensive statement of the nature of current map resources for the partially seeing in relation to general cartographic design and is the only one concerned with quantitative testing of an array of alternative designs of maps for use by those with highly restricted vision. The careful presentation of the rationale and design of the testing system as well as the utilization of several analytical techniques have paved the way for future extensions of this study as well as application to related types of problems. In addition, the study constitutes a significant contribution to cartographic theory through its analysis of the similarities and differences in design problems involved in creating maps for use by those with normal and highly restricted sight. The findings and recommendations embodied in this study have helped to develop and prove methods and the organization of future research which could result in the creation of maximally efficient maps and graphics for partially seeing children.

DISSERTATION READING COMMITTEE:

MAP DESIGN FOR PARTIALLY SEEING STUDENTS;

AN INVESTIGATION OF WHITE VERSUS BLACK LINE SYMBOLOGY

by

GERALD LEE GREENBERG

A disseration submitted in partial fulfillment

of the requirements for the degree of

DOCTOR OF PHILOSOPHY

VOLUME 1

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1968

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CHAPTER I

INTRODUCTION

This study is the first known attempt to systematically investigate selected elements of design of maps prepared for persons having severe visual impairments or "partial sight". During the past several decades there has been much experimental research and development of large-print textbooks produced for "sight-saving classes" attended by partially seeing students of primary and secondary school ages. Large-print books also have been prepared for special vocational schools and special library collections which are maintained for partially seeing adults. Special local, state and national agencies in most culturally advanced countries have been concerned with the design and production problems of textual materials, especially prepared for the partially seeing segment of the population which is increasing in numbers annually. In the United States such agencies include the Department of Health, Education, and Welfare, Office of Education (Washington, D.C.), the National Society for the Prevention of Blindness, Incorporated (New York, N.Y.), the American Foundation for the Blind, Incorporated (New York, N.Y.), National Aid to Visually Handicapped (San Francisco, Calif.), the American Printing House for the Blind, Incorporated (Louisville, Ky.) and Stanwix House, Incorporated (Pittsburgh, Pa.). Though all of the above agencies and

others have significantly contributed to the development and production of standard large-print textual materials, none has yet attempted to determine design standards and production methods relating to graphic materials such as diagrams and maps that are often needed to complement or supplement printed text. It is well established, however, that partially seeing students throughout the United States and in many other countries such as Japan receive educational benefits from specially made graphic materials as well as from large-print textbooks used in sight-saving classes.[1] In order to teach these students the fundamental facts and concepts about geography, geology, meteorology, astronomy, history and other physical and social sciences, it is often necessary employ graphic communication media such as maps. Specially prepared maps are particularly needed by partially seeing students for educational purposes. There are also recreational needs such as travel-guide and park-guide maps, and, as partially seeing students graduate into the adult world, professional-technical demands for specially prepared

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[1]Helen Gibbons, "Low Vision Aids -- The Educator's Responsibility," The Education of the Blind, V. 12, n. 4 (May, 1963), pp. 107-109; H. Iwahashi, Educational Director, Annual Report of Nippon Lighthouse 1961-1964, Osaka, Japan: Nippon Lighthouse, Welfare Center for the Blind (1964), p. 6.

thematic maps might readily arise. Hence, it is hoped that this study will begin to fill a vital gap in the development of low-vision cartographic aids.

Partially Seeing Students and Their Cartographic Needs

Clinical and Legal Definition of Partial Sight. Individuals with central visual acuity that falls within the Snellen vision test range between 20/70 and 20/200, after maximum medical correction in the better eye, may be classified as partially seeing.[2] In most countries including the United States, the standard legal definition of partially seeing individuals usually is defined within this Snellen vision test

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[2]Dena Motley, Our Visually Handicapped Children, Public Information Series No. 3, Lawrence, Kan.: Univ. of Kansas (1960), pp. 1-3; Problems of the Partially Seeing, San Francisco: National Aid to Visually Handicapped (1967), pp. 2-3; Natalie Barraga, Increased Visual Behavior in Low Vision Children, Research Series No. 13, New York: American Foundation for the Blind, Inc. (1964), pp. 3-5; Winifred Hathaway, Education and Health of the Partially Seeing Child, Fourth Ed., New York: published for the National Society for Prevention of Blindness, Inc. by Columbia Univ. Press (1959), pp. 15-18.

range.[3] The Snellen vision test measurement of 20/70 simply means that the individual can see at 20 feet what others, with "normal" vision, see at 70 feet; and 20/200 means that the person sees at 20 feet what others, with "normal" vision, see at 200 feet. Snellen's formula, used to describe acuteness of central vision, expressed a comparison of the visual acuity of the person being tested with the visual acuity of the "normally" seeing person: V=d/D.[4]

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[3]A contraction of the visual field to 20 degrees or less in the widest diameter, sometimes termed tunnel vision, also is criteria for defining both blindness and partial sight. Legal definitions are found in: Gabriel Farrell, The Story of Blindness, Cambridge: Harvard Univ. Press (1956), pp. 208-219; Gerald Fonda, "Definition and Classification of Blindness with Respect to Ability to Use Residual Vision," The New Outlook for the Blind, V. 55, n. 5 (May, 1961), pp. 169-172; John W. Jones, Blind Children, Degree of Vision, Mode of Reading, Bulletin No. 24, Washington: U.S. Dept. of Health, Education, and Welfare, Office of Education - U. S. Government Printing Office (1961), p. 3; U. S. Congress, Social Security Act of 1935, as amended, Title X, Definitions of Blindness; and U. S. Congress, Federal Act to Promote Education of the Blind, as amended by Public Law 922, 84th Congress, 2nd Session, (1956) Excerpts from State Laws and Regulations Defining Exceptional Children and Youth, Including Specific References to the Visually Handicapped, Washington: U. S. Dept. of Health, Education and Welfare, Office of Education (May, 1960), 16 pp.

[4]Normal or standard limits of visual acuity were determined from an averaged visual acuity sampling of a large population. Visual acuity was defined by Snellen as "the minimal distance at which two simulataneous impressions give rise to two independent sensations." This relation should not be confused with measurements of visual efficiency, defined by medical authorities as "the competence of the eyes to accomplish their physiological functions." This "competence" is often expressed as a "percent of central visual efficiency" or as a "percent loss of visual efficiency," and these percentage values have been given standard relations to specific Snellen ratings of visual acuity. See Gabriel Farrell, "Herman Snellen and the Letter E," The Education of the Blind, V. 14, n. 2 (Dec., 1964), pp. 56-59; see also Motley, op. cit., pp. 1-2.

V means visual acuity of the person being tested, d is the distance of the person from the Snellen eye test chart, and D is the distance at which the standard rows of letters on the chart are clearly read by persons with "normal" vision. Thus, a person with 20/70 visual acuity must be within 20 feet of an object or image that a normally seeing person can see from a distance of 70 feet.

Persons who need special medical and educational services due to visual impariments, either temporarily or on a long-term basis, may be classified medically and/or legally as partially sighted. Such persons may have a progressive eye difficulty, muscular eye restrictions or physical damage to parts of the eye. These individuals having either genetic or acquired vision defects may or may not have visual acuity falling within the above stated Snellen test range.[5] The majority of cases of defective vision involve errors in the refractive system (lens) of the eye. These errors may be classified as (1) hyperopic in which parallel rays of light focus behind the retina and must be compensated by convex or "plus" lenses, (2) myopic in which parallel rays of light focus in front of the retina and must be compensated by concave or "negative" lenses and (3) astigmatic in which

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[5]Committee on Child Health of the American Public Health Association and the National Society for the Prevention of Blindness, Inc., Services for Children with Vision and Eye Problems, New York: American Public Health Association (1956), pp. 13-14.

parallel rays of light fail to come to a focus at a point and must be compensated by cylindric lenses, either convex or concave, placed in a proper correcting polarity. Also, as indicated above, a number of cases of defective vision result from muscular disorders and physical damage or deficiencies. Lists of medical nomenclature for some of the more common visual impariments appear in the reference books noted below and in other medical books.[6]

Besides the standard Snellen vision tests (letter and E symbol charts), there are several other tests used for indicating visual dificiencies which may be diagnosed as partial sight. One of these tests is called the Jaeger test. This device has twenty sizes of reading type printed on a small card which is used for testing the accommodative ability of the eyes at short distances. This test is done by checking near vision reading ability at a distance of 14 inches from the eye.[7] There is also a modified Snellen test used for highly accurate determination of the distance acuity of visually handicapped

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[6] Matthew Luckiesh and Frank K. Moss, Reading as a Visual Task, New York: D. Van Nostrand Co., Inc. (1942), pp. 273-309; James Southall, Introduction to Physiological Optics, London: Oxford Univ. Press (1937), pp. 128-163; see also Hathaway, op. cit., pp. 147-169, E. M. Hatfield, Causes of Blindness in School Children, Publication P-609, New York: National Society for the Prevention of Blindness, Inc. (1964), 16 pp.; and Ralph G. Hurlin, 1960 Revision of the Standard Classification of the Causes of Blindness, Publication P-114, New York: National Society for the Prevention of Blindness, Inc. (1960), 4 pp.

[7] Farrell, op. cit., (footnote 3), p. 58: The Jaeger Eye Test, Buffalo, N. Y., American Optical Co., (1960)

persons.[8] Eye muscles are checked for balance and fusion capabilities (ability of the two eyes to work together) by the Maddox lens test, or by using stereoscopic or color and tonal positioning devices.[9] Color deficiencies do not ordinarily justify classifying a person legally blind or partially sighted. However, some persons occasionally are specially classified as partially seeing due to pigment deficiencies which require special testing and therapeutic needs.[10] Physiological conditions such as lens deformities, corneal damange, and retinal and pigment deficiencies are diagnosed by opthalmologists. These doctors have the ultimate authority and responsibility of diagnosing an individual as partially seeing, medically and legally. Such diagnosis may vary considerably from the definition mentioned earlier, and this definition may also vary considerably from one geographic region to another, depending upon local medical and legal standards. A medical diagnosis

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[8] A Guide for Screening Visual Acuity with Modified Snellen Chart, Publication P-201, New York: National Society for the Prevention of Blindness, Inc. (1962), 4 pp.

[9] Vision Screening in the Schools, Publication P-257, New York: National Society for the Prevention of Blindness, Inc. (1965), pp. 4-5; Florence Cunningham, The Massachusetts Vision Test Battery, Publication P-204, New York: National Society for the Prevention of Blindness, Inc. (1963), 8 pp.; Albert E. Sloane, "Massachusetts Vision Test: An Improved Method of Testing Eyes of School Children," Archives of Ophthalmology, V. 24, n. 5 (Nov., 1940), pp. 924-939.

[10] A congenital and hereditary deficiency of pigment known as albinism may cause a severe vision impairment. Hathaway, op. cit., p. 161. Color vision tests are described in Dean Farnsworth, Color Vision, Publication P-608, New York: National Society for the Prevention of Blindness, Inc. (1961), 8 pp.

statement normally is required by partially seeing individuals in order to receive national or state (public) welfare benefits such as enrollment in sight-saving classes and special vocational schools.

Map Requirements for Partially Seeing Students. State and local school programs throughout the United States report that they find one visually handicapped child for every 1000 to 1500 students.[11] The proportion of persons with low visual acuity fluctuates between 0.3 and 1.2 to every 1000 persons in all countries, according to past surveys. Japan, for example, had a ratio of 1.22 weak-sighted persons per 1000 in the year 1934.[12] Crude estimates indicate that there are between 75,000 and 100,000 children of school age in the United States whose visual performance is enough below normal to require special educational services in "sight-saving classes". The Office of Education, U. S. Department of Health, Education, and Welfare reports that as of 1966, there were at least 23,000 partially seeing students enrolled in special education programs in public and private schools

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[11] John W. Jones, The Visually Handicapped Child at Home and School, Bulletin No. 39, Washington: U. S. Dept. of Health, Education and Welfare, Office of Education - U. S. Government Printing Office (1963), p. 38; John W. Jones, Educational Programs for Visually Handicapped Children, Bulletin No. 6, Washington: U. S. Dept. of Health, Education and Welfare, Office of Education - U. S. Government Printing Office (1966) p. 23.

[12] M. Bartels, "Sight Saving Classes," Sight Saving Review, V. 11, n. 9 (Mar., 1939), pp. 23-24.

throughout the United States.[13] Survey estimates also indicate that fewer than 8100 of the students enrolled in sight-saving classes have adequate educational facilities provided for them.[14]

An intensive survey of special educational maps and other types of maps available to partially seeing students and adults reveals that there is an acute lack of cartographic aids provided for persons with visual handicaps. Often, regular maps are used with the aid of illuminated magnifying lenses, optical projectors, and image enhancement by means of the application of bright colors and grease pencil lines. The limited number of special map aids that are commercially produced ordinarily have design characteristics which are empirically determined. The "trial-and-error designs" of these maps are possibly better than none at all, and they do give the cartographic researcher some design clues as well as a basis for future developmental comparison. Numerous complaints, however, from both partially seeing students and their teachers indicate that better, "more readable" map

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[13] Hathaway, op. cit., pp. 33, 137; "Visually Handicapped, Total Enrollment, Public and Private," Digest of Educational Statistics, Washington: U. S. Dept. of Health, Education, and Welfare, Office of Education - U. S. Government Printing Office (1966).

See also R. G. Harlen, "Estimated Prevalence of Blindness in the United States and in Individual States," Sight Saving Review, V. 32 (Spring, 1962), pp. 4-32; and Hyman Goldstein, "Blindness Register as a Research Tool," U. S. Public Health Reports V. 79, n. 4 (Apr., 1964), p. 289.

[14] Problems of the Partially Seeing, San Francisco: National Aid to Visually Handicapped (1967), p. 4.

designs are needed. Some of the more exigent complaints about available maps are: "the symbols are too small," "the symbols are too dim," "the maps are too cluttered with symbols and writing," "the maps have the wrong kinds of symbols," "the size of the map sheets are too small," "there are too many colors on the maps," and "there aren't enough different kinds of maps produced."

These criticisms suggest that there is a dire need for basic, experimental cartographic research on the design elements of maps produced for partially seeing persons. It cannot be assumed that empirically designed maps, and "modifications" of the viewing conditions and designs of maps produced for normally seeing persons will result in the production of optimally readable maps for partially seeing persons.

Between 1966 and 1968 the author personally examined and received comment on map materials being used in seven different special-vision classes (sight-saving classes) in public schools in Seattle, Washington and vicinity.[15] Also during this time, extensive mail inquiries were made to major agencies in the United States, Europe and Asia dealing with vision problems, and to agencies producing

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[15]Schools visited in Seattle, Washington and vicinity are listed in the Acknowledgments in the Preface pages. Other agencies visited include the Braille Institute of America, Inc., and the Blind Rehabilitation Section of the Veterans Administration Center, both in Los Angeles, California.

special educational materials for visually handicapped persons. Only three agencies indicated that they produced maps for partially seeing persons, and these maps were empirically designed, simple outline maps.[16] Most replying correspondents recommended direct use or modification (enhancement) of standard outline maps, wall maps, and raised relief maps, globes and models - a "do-it-yourself" approach to designing and producing maps for partially seeing persons. Lack of design criteria, high production expense and small market were reasons chiefly cited for lack of production of such maps.[17]

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[16] "Large Type Outline Map of the USA," Louisville, Kentucky: American Printing House for the Blind, Inc.; "United States Study Maps," and "United States - Outline Study Maps," Pittsburgh, Pennsylvania: Stanwix House, Inc.; and "Set of Maps and Charts from Living in Today's World," San Francisco, California: National Aid to Visually Handicapped.

[17] Correspondence with agencies including: American Printing House for the Blind, Inc., Louisville, Ky.; Stanwix House, Inc., Pittsburgh, Pa.; National Aid to Visually Handicapped, San Francisco, Calif.; American Foundation for the Blind, Inc., New York, N.Y.; National Society for the Prevention of Blindness, Inc., New York, N.Y.; American Association of Workers for the Blind, Inc., Washington, D. C.; Xavier Society for the Blind, New York, N.Y.; The Westchester Lighthouse, New York, N. Y.; Division for the Blind, The Library of Congress, Washington, D. C.; Office of Education, U. S. Dept. of Health, Education and Welfare, Washington, D. C.; Research Dept., The Library Association, London; Nippon Lighthouse, Welfare Center for the Blind, Osaka; American Foundation for Overseas Blind, Paris; Royal National Institute for the Blind, London; Blindenstudienanstalt, Marburg-Lahn; Imprimeri Nationale des Aveugles Belges, Brussels. Major American map companies including Rand McNally & Co., A. J. Nystrom & Co., and Denoyer-Geppert Co., all in Chicago, Ill., and the George F. Cram Co., Indianapolis, Ind., also were contacted by mail.

A Hypothesis on Map Design for Partially Seeing Students

During the period from April through June, 1965, experimental investigations on problems of designing maps for partially seeing students were initiated by the author through the cooperative participation of the Special Education Department of Worth McClure Junior High School, Seattle, Washington.[18] One experiment on relative levels of symbol and background contrast indicated that many of the partially seeing students could more effectively discriminate the symbology on maps at greater viewing distances if the symbols were printed in white on a dark background, instead of the conventional black printing on a light background, Hence, some fundamental research questions arose from this observation: (1) which arrangement of symbol versus background produced the most readable maps for a majority of partially seeing students, and (2) how much better was one combination versus the other in terms of viewing distance advantage? Also, a question of symbol dimensions was implicit in

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[18] Requests for developmental aid in making maps for partially seeing students were made by Mrs. Marjory Swanson, Instructor in Special Education at this School. She first communicated her problem to Professor John C. Sherman of the Department of Geography, University of Washington, known for his research on maps for the blind. An array of desk map samples containing a variety of design formats were prepared by students in an advanced cartography class. These map samples were used for the first exploratory testing.

the above mentioned observation: (3) if white symbols were more readable at equal or greater viewing distances than black symbols, then could white symbols printed on a black background be drawn at smaller dimensions than similar black symbols printed on a white background, and would these smaller-sized white symbols be as readable or more readable than the larger-sized black symbols? A final question relating to the level of symbol to background contrast also arose: (4) if white symbols printed on a black background were more readable than equivalent black symbols printed on a white background, then would white symbols printed on certain gray-toned backgrounds also be more readable than black symbols printed on a white background?

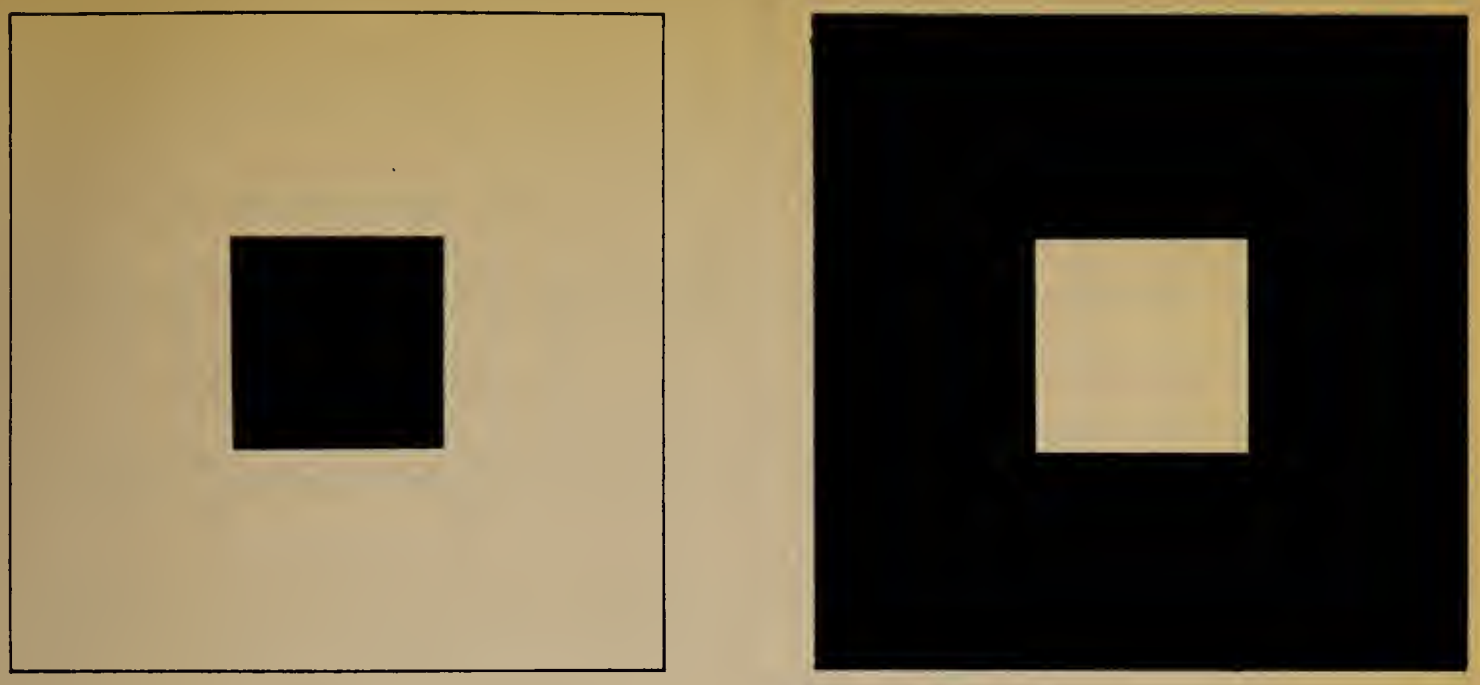
These research questions may be restated, with qualifications, as the hypothesis of this dissertation. Hence, this study will attempt to determine, for a varied sampling of partially seeing students, whether maps with white line symbology printed on black or gray backgrounds are more readable at equivalent or greater viewing distances than are maps with identical black line symbology printed on a white background. Also, this study will attempt to determine if maps designed for partially seeing students can be drawn with thinner line symbology, if this symbology is printed in white on a black or gray-toned background instead of the conventional black printing on a white background.

Line symbols were selected for investigation in this study because on individual outline maps they appear in greater quantity than point, area and notational symbols. Readable outline maps are basic teaching aids which are urgently needed in sight-saving classes.

Related Research: The Irradiation Illusion

Definition and Effects. The principle reason why thin white images on dark backgrounds sometime seem to appear more legible than equally-sized thin black images on light backgrounds, at the same viewing distance, is a perceptual phenomenon called light irradiation. This irradiation (or halation) phenomenon is expressed in the visual illusion where black images appear narrower on a white background and white images appear wider on a black background. In the latter case, the white appears to "spread out" or "spill over," leaking into the contrasting black surroundings, and producing an illusion of image magnification or enhancement (see Figure 1). It seems that the apparent increase in white area is made at the expense of the adjacent black area. This phenomenon is strongest when the image brightness is most intense, and it is also strongest when visual accomodation is imperfect. Visual irradiation has been physiologically defined as the lateral diffusion or adaptation of light stimuli beyond the actual stimulus limits of the image on the receptors in the retina of the eye. Helmholtz showed that this effect is due to blurred or

A



B

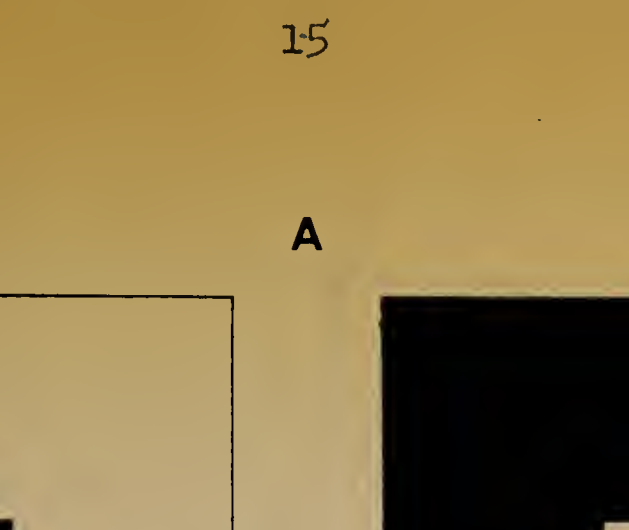


Figure 1. Irradiation (Halation) Illusion Examples.
A-The inner two squares are of equal size, but the light one appears slightly larger than the dark one;
B-The white strip on the dark background appears slightly wider than the dark strip on the bright background, although both strips are of equal dimensions. The illusion may become more vivid by rotating the page or viewing axis 90 or 180 degrees.

oversaturated visual stimuli. For example, an apparent image magnification may be experienced when the eyes are subjected to extremes of contrast such as viewing the stars or the crescent of the new moon on a dark night. A very intense light source viewed at night may appear to be many times larger than its actual physical size. A reversal of the effect also may be noticed, such as in a situation where the dark trunk of a tree is viewed against bright sunlight - the tree trunk might appear much thinner than its actual physical size.[19]

Graphic Research. A number of relatively recent image-background (simultaneous contrast and irradiation illusion) studies, especially those by Berger, indicate a distinct viewing distance advantage for narrow stroke-width numerals printed on a black background, versus similar black numerals printed on a white background. (Stroke-width, as used by Berger, is the ratio of the thickness of the stroke or body to the height of letter or numeral.) The study by Berger compared the legibility of black numerals on license plates

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[19]Hermann L. F. von Helmholtz, Handbuch der Physiologischen Optik, Hamburg and Lipzig: Verlag von Leopold Voss (1896), pp. 395, 400; M. Luckiesh, Visual Illusions, New York: D. Van Nostrand Co., Inc. (1922), pp. 114-123; James P. Southall, Introduction to Physiological Optics, London: Constable and Co., Ltd. (1937), p. 404; S. Tolansky, Optical Illusions, Oxford: Pergamon Press, Ltd. (1964), pp. 59-70; Maitland Graves, Color Fundamentals, New York: McGraw-Hill Book Co., Inc. (1952), p. 109; Five varieties of visual irradiation are described in F. P. Boswell, "Irradiation of Light," Psychological Bulletin, V. 2 (1905), p. 200. Some other causes of irradiation have been attributed to spherical aberration in the eye lens, diffraction of light at the pupil of the eye, and special attributes of radiation such as polarization.

having white backgrounds to the legibility of white numerals on license plates having black backgrounds. Many similar studies have extended Berger's investigations to other graphics such as highway and airport signs and markers. The widths or body of most line symbology on maps produced for desk use may vary between 0.1 millimeter and 1.5 millimeters (approximately 0.005 inch to 0.060 inch). The findings of Berger and others indicate that a 15 percent or greater viewing distance advantage can be obtained for letter-number displays having narrow white symbols (printed on a black background) with body weights measuring within the above-mentioned line-width range for desk maps.[20] Hence, it is quite probable that maps designed with white line symbols printed on a dark gray or black background may exhibit extended viewing distance characteristics similar to those indicated in the studies on letter- number displays.

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[20] Julius E. Uhlaner, "The Effect of Thickness of Stroke on the Legibility of Letters," Proceedings of the Iowa Academy of Science, V. 48 (1941), pp. 319-324; Curt Berger, "Stroke-width, Form and Horizontal Spacing of Numerals as Determinants of the Threshold of Recognition," Part I, Journal of Applied Psychology, V. 28, n. 3, (June, 1944), pp. 208-231, and Part II in same journal, V. 28, n. 4 (Aug., 1944), pp. 336-346; H. W. Case, et. al., "Analysis of Certain Variables Related to Sign Legibility," Highway Research Board Bulletin, No. 60, (Jan., 1952), pp. 44-54; Terrance M. Allen and Arthur L. Straub, "Sign Brightness and Legibility," Highway Research Board Bulletin, No. 127 (Jan., 1955), pp. 1-14; Delbert F. Karmeir, et. al., "A Comprehensive Analysis of Motor Vehicle License Plates," Highway Research Board Proceedings, V. 39 (196), pp. 416-440; and C. Gordon Herrington, "Design of Reflectorized Motor Vehicle License Plates," Highway Research Board Proceedings, V. 39 (1960), pp. 441-466.

Graphic Applications. In areas of graphic communication, negative printing techniques (white images printed on black, dark gray or colored backgrounds) are frequently employed in art and advertising displays, blueprinting, negative photostating, and in the form of common blackboard writing. Only occasionally, however, are applications of negative printing found in cartography. Whenever used in map design, this technique usually permits the addition of extra, highly discriminable symbology, such as in the printing of white map grid lines on a blue ocean background, thus leaving the use of black line symbols for representation of ocean navigation routes and boundaries. In this example, an extra "color" coding symbol has been added to a two-color map printing. Radar superposition navigation maps used during World War II were designed in a negative fashion so that the white radar scope images could be projected onto, and compared with the special white map symbols printed on black or dark gray background compositions.[21] It is significant to note that by employing modern photomechanical techniques of map reproduction, the time and cost factors are about equal to produce small or large quantities of maps with either standard or negative-like symbology.

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[21] John S. Hall, Ed., Radar Aids to Navigation, New York: McGraw-Hill Book Co., Inc. (1947), pp. 335-353; see also USAF Radar Charts, Series RC, and Aeronautical Video Plates, Series AVP, St. Louis, Mo.: U.S.A.F. Aeronautical Chart and Information Center.

Research Objectives, Limitations and Methods

Objectives and Limitations. The objectives of this study, as indicated by the hypothesis statements are to determine if there are viewing range increases and/or symbol dimension reduction advantages for maps designed with white line symbols printed on dark backgrounds, as compared with maps having black line symbols printed on a white background. These objectives also may be stated in another manner: to determine if a reversal of contrast between map line symbols and map background (a change from conventional black lines on a white background to a negative-like map display containing white lines on a black or gray background) will effect viewing range increases and/or symbol reduction advantages. If the hypothesis is valid, then a new basis for the development of map design criteria for partially seeing students would be established. Also, such new design criteria might have applications in the production of ordinary maps and graphics.[22]

This study is intended only to determine trend indications relating to this hypothesis, and cannot be considered conclusive,

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[22]Partially seeing persons ordinarily read large-print text and graphics at a 7 inch viewing distance. Increasing the viewing distance would increase the scanning field, and decreasing image size would reduce image clutter or undesirable interactions.

since there are a number of limitations restricting the comprehensiveness or scope of the work. First, one should especially note that this study only investigates a limited number of map line symbols, line symbol dimensions, backgrounds and viewing distances.[23] Another limit is the number and types of partially seeing students available for experimental testing of the map materials used in this study. Budget and time limitations restricted the study area of this dissertation to Seattle, Washington and vicinity, where 43 partially seeing students of varied clinical diagnosis participated in this study. These students could not be gathered in one place for the experimental map test used in this study, so it was necessary to carry on tests for small groups of students in their respective classrooms at specially approved time periods. Only one test session per group of students was possible due to limited access time. Needless to say, the environmental conditions from one classroom to another were somewhat different, but all classrooms did have similar illumination conditions and conventional furnishings. Limitation in the quality of production of map test materials employed in this project also bears mention. Due

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[23] Specific line symbols, and test variables including linewidths, backgrounds and viewing distances, as well as other map parameters, subject population characteristics and control measures used in this study are described in detail in the next chapter on Map Test Rational, Design and Production.

to budget restrictions it was necessary to use Ozalid printing rather than higher quality offset printing for producing the special maps and forms utilized. Also, due to the above restriction, it was necessary to employ hand rather than machine construction and assembly of the test materials. This procedure resulted in well made, highly reliable map test equipment, but imposed a tremendous loss of precious research time. A final limitation to this study is the method of analysis of the test data. Due to the limited number of map test variables and small and varied map test population, the summary and analysis of test response data was done by descriptive, statistical mean, rank, and trend methods. These procedures were augmented by a large number of specially designed tabular displays depicting raw data, mean data and graphic trends, as well as by several statistical tests.

Research Method. This study employs a psychophysical research method. For purposes of this dissertation, this method is defined as a systematic map test procedure by which subject response trend effects from specially designed, interacting map elements (variables) are measured under prescribed conditions of environment and subject control. Such a procedure is relatively new in the field of experimental cartography, but since World War II it has been fast replacing the old artistic, intuitive, trial-and-error methods of investigation which fail to provide quantitative, predictive evaluations of map

design.[24] The psychophysical approach to research and development of graphic display systems is commonly employed in the fields of experimental perception psychology and human factors engineering.[25]

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[24]S. S. Stevens, "On the Psychophysical Law," Psychological Review, V. 64, n. 3 (May, 1957), pp. 153-181; Examples of some map studies employeing a psychophysical approach include the following: Gosta Ekman, "Psychophysical Relations in Visual Perception of Length, Area and Volume," Scandinavian Journal of Psychology, V. 2 (1961), pp. 1-10; Gosta Ekman and Ralf Lindman, "A Psychophysical Study of Cartographic Symbols," Perceptual and Motor Skills, V. 13, n. 3 (Dec., 1961), pp. 355-368; R. L. Williams, Statistical Symbols for Maps: Their Design and Relative Values, Report on project research under Contract NR 008-006, Nonr 609(03), New Haven, Conn.: Yale Univ. Map Lab., and Washington, D.C.: U. S. Office of Naval Research (Mar., 1956), 115 pp.; R. L. Williams, "Map Symbols: Equal Appearing Intervals for Printed Screens," Annals of the Association of American Geographers, V. 48, n. 2 (June, 1958), pp. 132-139; O. M. Miller, An Experiment in the Systematic Use of Color in Cartography, Report on research under Contract AF 33(616) 2378, Osurf Proj. No. 595, Tech. Paper No. 213, Columbus, Ohio: Ohio State Univ Mapping and Charting Research Lab. (Sept., 1957), 32 pp.; Charlotte A. Christner and Horace W. Ray, "An Evaluation of Selected Combinations of Target and Background Coding on Map Reading Performance," Human Factors, V. 3, n. 2 (July, 1961), pp. 131-146; A. Koponen, R. H. Waters and J. Orlansky, The Associational Value of Aeronautical Chart Symbols, Report on research under Contract N8 ONR-641, Task Order 05, Stamford, Conn.: Dunlap and Associates, Inc. (July, 1952), 36 pp.; J. P. Kishler, R. H. Waters and J. Orlansky, The Development of Graphic Aids to Air Navigation, Report No. 641-05-1 on research under Contract N8 ONR-641, Stamford, Conn.: Dunlap and Associates, Inc. (May, 1951), 27 pp.; W. H. Lichte, Psychological Studies of the Content and Methods of Presenting Charts and Maps for Radar Observers and Navigators, Report on research project No. 7738 under Contract AF 18(600), Randolph AFB, Texas: USAF Operator Lab. (Jan., 1958), 20 pp.; Many other studies listed in Human Engineering Bibliography, Search Title - Maps, 3.10.2, published annually by Project Staff, Human Engineering Information and Analysis Service, Institute for Applied Experimental Psychology, Tufts Univ., Medford, Mass., Washington, D. C.: Office of Naval Research, U. S. Dept. of the Navy.

of graphic display systems is commonly employed in the fields of experimental perception psychology and human factors engineering.[25]

Material Organization. The material in this dissertation is arranged in three principal chapters, a brief concluding chapter and an appendix volume. In this chapter an attempt has been made to define the dissertation research problem, indicate the dissertation objectives and limitations and to introduce the methods of research and analysis employed. The second chapter contains information on the derivation, design and production of a map test. This test is used as a means of determining how partially seeing students react to different combinations of map symbol line-width dimensions, map backgrounds and map viewing distances. The third chapter contains descriptive analysis of the results of the map test, including complete map test data record tables, graphic tables illustrating averaged subject response trends and statistical tests of significance of response data. In the concluding chapter some tentative design

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[25]Harry H. Poole, Fundamentals of Display Systems, London: Macmillan and Co., Ltd. (1966), 403 pp.; Wesley E. Woodson and Donald W. Conover, Human Engineering Guide for Equipment Designers, Second Ed., Berkeley, Calif.: Univ. of Calif. Press (1964), Ch. 3, Vision; Ernest J. McCormick, Human Factors Engineering, New York: McGraw-Hill Book Co., Inc. (1964), Ch. 6, Information Displays, and Ch. 13, Illumination.

specifications for maps for partially seeing students are given. These specifications are based on the map test trend analysis. Also included are suggestions on map production techniques, and proposals for future investigations and extensions of this project. The appendix volume contains a sample of the map test, the map test compilation matrices and viewing distance spacing apparatus.

CHAPTER II

MAP TEST RATIONALE, DESIGN AND PRODUCTION

The essential purpose of the map test was to measure the accuracy with which subjects could perform an assigned task utilizing map test samples which were of uniform geographic area coverage, but varied in their individual visual characteristics. The major visual differences between the various test maps which were designed and utilized, were the line-width of symbols and the symbol-to-background contrast relationships. The subject's performance of the assigned task (counting of a specially selected symbol on all test maps) is the principle response data for forming a judgment as to the relative readability of the different maps employed in the map test. The tests were also designed to determine whether or not the hypothesis on the effects of the irradiation illusion in maps designed for partially seeing students was applicable.

This chapter contains a description of the derivation, design and production of a map test for partially seeing students. Small scale, desk-type outline maps are employed in sight-saving classes more frequently than any other cartographic aid. Most of the symbols on these outline maps are line symbols, including map border and grid lines (latitude and longitude lines), coastlines, rivers, boundaries and transport routes. For these reasons, specially designed versions of

an outline map of the state of Washington were employed in the map test.[1] The initial section of this chapter contains information on the rationale, derivations, functions and specifications of the map test symbology and backgrounds. In the second section, procedures of test compilation and control are described, including information on the map test subject population. The final section contains a description of the methods of assembly and reproduction of the map test, as well as reference information on the equipment and materials utilized.

Derivation of Experimental Map Specifications

Symbol Selection, Functions and Dimensions. Different kinds of line symbols which appear in the same fixed position on all of the test maps include the map border, grid lines for every one degree of latitude and longitude, coastlines, major rivers, and state and county boundaries (see Figure 3, page 34, and Map Test Booklet sample, Volume 2, Appendix). These types of line symbols were arbitrarily selected on the basis of the simplicity of their structure and the ease

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[1] This map area was selected because all of the test subjects, who are residents of the state of Washington, would have a commonly familiar test map which would simulate reality and ease anxiety in the classroom during testing periods. The map base data compilation source is the Washington State Outline Map, No. DD 146, Chicago: A. J. Nystrom & Co., map scale - 1:2,000,000 (approximately 1 inch to 32 miles), Alber's conic, equal-area projection.

of their individual identification when all of these symbols are viewed together on one map. Straight, solid map border lines appear in the same position on all test maps, and these lines serve only to frame the map area which measures 9.5 inches (24.15 centimeters) by 13.15 inches (33.45 centimeters). The map grid lines also appear as solid line symbols, systematically spaced at one degree intervals at the same positions on all test maps. Latitude lines are slightly curved lines which horizontally traverse the map area, and longitude lines are straight lines which vertically traverse the map area. Rivers and coastlines are drawn in the same position on all of the test maps, and these lines appear as variably curved, solid line symbols. Boundary lines appear as both straight and curved dashed lines, the dashes averaging between 2 and 3 millimeters in length, and spaced from 1 to 2 millimeters apart. The same dashed line symbol is used to represent all county, state and international boundaries which appear at fixed positions on all of the test maps. In certain instances where the positions of boundary and grid lines coincide, the dashed boundary lines are drawn in lieu of grid lines, and in such instances the dashed lines are to be interpreted as boundary lines.

Arrow symbols, which intersect with either grid lines, boundaries, or rivers and coastlines, were particularly selected to be plotted at <u>varied</u> positions on the test maps. Since these symbols sharply contrast with the longer, fixed position line symbols, they

were useful in the formulation of a visual task which is the essence of the map test. The arrows have no special meaning other than an indefinite directional connotation. Therefore, no specific inferences might be interpreted from their varied map positions and intersections with the fixed-position map symbols, except for the frequency of intersection between the arrows and the other map symbols. This frequency of intersection creates a basis for the design of the map test; i.e., the subject's visual task of counting on each test map the number of times that arrow symbols intersect with boundary lines, rivers and coastlines, and latitude and longitude lines. A measure of the readability of the different test maps is thus achieved by evaluating the accuracy with which the test subjects are able to count the arrow symbols which intersect with the fixed-position map base symbols at varied locations on the test maps.[2] The arrow symbols have straight shafts which are 0.4 inches (10.16 millimeters) in length. The arrow-head barbs are 0.12 inch (3 millimeters) long, and they connect with the arrow shaft at angles of 45 degrees. The arrows point away from the line symbols which they intersect, and only the ends of the arrow

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[2]See Map Test Booklet, Volume 2, Appendix for specific map test instructions concerning arrow counting. Also refer to the second part of this chapter on Map Test Design and Use, Test Compilation. Symbol evaluation procedures are described in Chapter III.

shafts touch those line symbols. These intersections are made at angles greater than 30 degrees in order to facilitate detection of the arrows.

Map scale and map area were two basic limits influencing the dimensions and the amounts of generalization of the configuration of the symbols on the test maps. At the relatively small map scale of approximately 1:2,000,000 (approximately 1 inch to 32 miles) it was necessary to smooth the irregularities of the rivers, and coastlines and boundaries. Smoothing of the hydrographic and boundary symbols, as well as selective shortening and deletion of sections of the rivers and coastlines, was undertaken in order to prevent overcrowding of the limited, page-size map area. The object (map) area, especially, influences the map viewing distance which in turn effects the dimensional requirements of map symbols. Books can be read relatively easily using a narrow scanning field at close range, but maps and other related graphics generally require a broader visual scanning field. Larger scanning areas require longer viewing distances. The increased distances required for efficient scanning of maps imposes a need for enhanced (thicker or magnified) line symbology which can be detected

and interpreted at these greater viewing distances.[3] Large-print textbooks are usually read by partially seeing students at viewing distances between 7 and 14 inches, although in certain instances the range may be as close as 1 inch or as far away as 30 inches from the reader's eyes. Viewing distances of 7, 14 and 21 inches (17.78, 35.56 and 53.34 centimeters) were selected as the three map test reading distances in this study. So-called normal reading distance is prescribed at 14 inches from the eyes, and this length is used as a

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[3]Matthew Luckiesh and Frank K. Moss, Reading as a Visual Task, New York: D. Van Nostrand Co., Inc. (1942), pp. 44-46, 126-153, 273-309; Harry H. Poole, Fundamentals of Display Systems, London: Macmillan and Co., Ltd. (1966), pp. 285-288, 292; Ernest J. McCormick, Human Factors Engineering, New York: McGraw-Hill Book Co., Inc. (1964), pp. 138-141, 152-154, 156-166; Wesley E. Woodson and Donald W. Conover, Human Engineering Guide for Equipment Designers, Second Ed., Berkely, Calif.: Univ. of Calif. Press (1964), pp. 2-10, 11, 40, 50, 74, 75, 129; H. Philip Zeigler and Herschel W. Leibowitz, "Apparent Visual Size as a Function of Distance for Children and Adults," ed. Herschel W. Leibowitz, Visual Perception, New York: The Macmillan Co. (1965), pp. 86-91; Matthew Luckiesh and Frank K. Moss, "Visual Tasks in Sight Saving Classes" American Journal of Ophthalmology, Series 3, V. 19, n. 10 (Oct., 1936), pp. 992-999; Harold E. Burtt, Typography and Readability," Sight Saving Review, V. 19, n. 3 (Fall, 1949), pp. 147-157; Gerald F. Rabideau, "Differences in Visual Acuity Measurements Obtained with Different Types of Targets," Psychological Monographs: General and Applied, V. 69, n. 10 (1955), pp. 1-12; W. M. Smith, "A Methodological Study of Size-Distance Perception," Journal of Psychology, V. 35, n. 1 (Jan., 1953), pp. 143-153; Donald G. Patterson and Miles A. Tinker, "The Effect of Typography Upon the Perceptual Span in Reading," The American Journal of Psychology, V. 60, n. 3 (July 1947), pp. 388-396; Arthur A. Robinson, "The Size of Lettering for Maps and Charts," Surveying and Mapping, V. 10, n. 1 (Mar., 1950), pp. 37-44.

standard when measuring near vision. A 0.045 inch (1.143 millimeters) line thickness was found to be the average body weight of most 24 point type styles employed in large-print textbooks (see Figure 2). This width of type was selected as a basic thickness specification for drawing the map test line symbols. Two other experimental line-widths were derived from the basic one by calculating 33 and 66 percent reductions of the basic dimension. Thus, 0.045 inch (1.143 millimeters) thick, 0.030 inch (0.762 millimeter) medium, and 0.015 inch (0.381 millimeter) thin experimental line widths were used in this study. These viewing distances and line-widths were derived from, and selected to conform with several sources of research information on standard printing specifications for the production of large-type reading materials for partially seeing students.[4]

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[4]Matthew Luckiesh and Frank K. Moss, Reading as a Visual Task, New York: D. Van Nostrand Co., Inc. (1942), pp. 44-46, 126-153, 273-309; Carson Y. Nolan, "Readability of Large Types," The Education of the Blind, V. 9, n. 2 (Dec., 1959), pp. 41-44; Gerald Fonda, "An Evaluation of Large Type," The New Outlook for the Blind, V. 60, n. 10 (Dec., 1966), pp. 296-298; William M. Eakin and Thomas L. McFarland, Type, Printing and the Partially Seeing Child, Pittsburgh, Pa.: Stanwix House, Inc. (1960), 16 pp.; William M. Eakin, Robert J. A. Pratt and Thomas L. McFarland, Type Size Research for the Partially Seeing Child, Pittsburgh, Pa.: Stanwix House, Inc. (1961), 32 pp.; Standards for Large Print Publications, San Francisco: National Aid to Visually Handicapped (1963), 11 pp.; Guidelines for the Production of Material in Large Type, New York: National Society for the Prevention of Blindness, Inc. (1965), 13 pp.

8 Point Type

Few parents realize that during the progress of these diseases the eyes of the patient may develop serious ulcers or other dangerous conditions, which, unless skilfully treated, may leave a white film over the "sight" of the eye

10 Point Type

Few parents realize that during the progress of these diseases the eyes of the patient may develop serious ulcers or other dangerous conditions, which, unless skilfully treated,

12 Point Type

Few parents realize that during the progress of these diseases the eyes of the patient may develop serious ulcers or other dangerous conditions, which, unless

14 Point Type

Few parents realize that during the progress of these diseases the eyes of the patient

18 Point Type

Few parents realize that during the progress of these diseases the

24 Point Type

Few parents realize that during the progress of these

30 Point Type

Few parents realize that during the prog-

Figure 2. Type Size Variations.
The 18 and 24 point sizes normally are used in books printed for partially seeing persons. Average line-widths for the 18 and 24 point type sizes are 0.035 inches (0.8 millimeters) and 0.045 inches (1.1 millimeters).

Background and Contrast Specifications. The map test symbols were printed in the three specified line-widths on backgrounds of white, light gray, dark gray and black (see Figure 3). These map backgrounds may be further identified by their respective Munsell color system equivalents; Number 9/White, Number 6/Medium Light Gray, Number 4/Medium Dark Gray, and Number 2/Grayish Black.[5] As indicated in Chapter I, the gray and black background tones function as irradiation fields for the negative-like white line images, so as to produce possible illusions of image magnifications. The amount of image magnification produced by the negative-like printing on each of the test maps with tonal backgrounds, as compared with the test maps having standard black printing on the white background, is measured by evaluating the accuracy with which the test subjects are able to perform certain visual tasks on the different test maps.[6]

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[5]Kenneth L. Kelley and Deane B. Judd, "The ISCC-NBS method of Designating Colors and a Dictionary of Color Names," U. S. National Bureau of Standards, Circular 533, Washington: U. S. Government Printing Office (Nov., 1955), pp. 81-82, 88, 110-112, 154; T. M. Cleland, The Munsell Color System, Baltimore, Md.: Munsell Color Co. (1937), pp. 7-8, and neutral Value chips on accompanying Color Notation Folio; Rock Color Chart, New York: The Geological Society of America (1963), plate 5, Value chips and names.

[6]Different subject response trends apparently resulting from different map backgrounds are described in Chapter III, Analysis of Map Test Results.

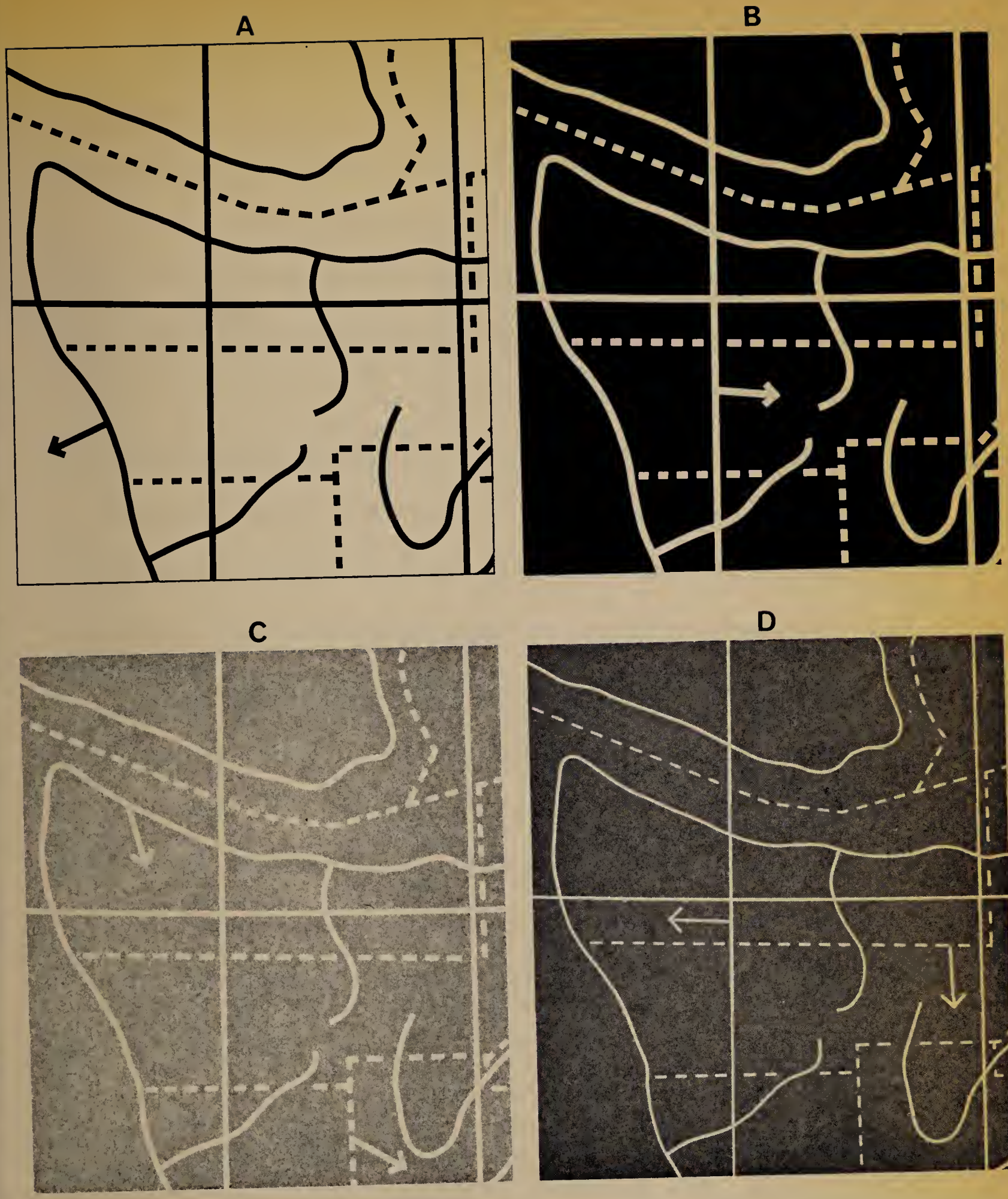

Figure 3. Map Test Background Cases and Line Widths.
Example sections of actual map test pages:
A-Black printing on white background (0.045 inch line-width);
B-White printing on black background (0.045 inch line-width);
C-White printing on light gray background (0.030 inch line-width);
D-White printing on dark gray background (0.015 inch line-width).

The color and surface finish of the paper upon which the map test symbols were printed produces contrast effects which influence the readability of the map symbols. A white, opaque paper card stock having a flat (non glossy) finish was selected as the map test printing media. This finish reduces glare from scattered and reflected light, thus improving the sharpness or edge-definition of the black map symbols. Almost all books, magazines and other graphics employ flat finish printing surfaces in order to reduce background glare which can cause eye fatigue and decreased visual acuity with respect to text and symbol perception. The use of a tinted (colored) printing surface would have added an additional factor (color) to the map test. The white background surface selected, thus permitted the printing of black symbols on a white background and also facilitated the printing of white symbols on black and gray tonal backgrounds. The subject of white versus tinted printing surfaces has received considerable discussion in the literature on textbook design for partially seeing students. Several experimental studies have concluded that, for the production of both standard and large-print textbook materials, there is no significant readability advantage achieved by printing either black or white text on colored page backgrounds. In fact, contrasting colored backgrounds, such as the once-popular pale-green and yellow tints, actually decrease

the perceivable contrast between text images and page background, thus decreasing the readability of the text.[7]

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[7] Matthew Luckiesh and Frank K. Moss, Reading as a Visual Task, New York: D. Van Nostrand Co., Inc. (1942), pp. 332-335, 221-236, 288; Matthew Luckiesh and Frank K. Moss, "Visibility and Readability of Print on White and Tinted Papers," Sight Saving Review, V. 8, n. 2 (June, 1938), pp. 123-134; R. B. Fishenden, "Types, Paper, and Printing in Relation to Eyestrain," Sight Saving Review, V. 16, n. 1 (Spring, 1946), pp. 51-57; Harold E. Burtt, "Typography and Readability," Sight Saving Review, V. 19, n. 3 (Fall, 1949), pp. 153-154; Carson Y. Nolan, "Legibility of Ink and Paper Color Combinations for Readers of Large Type," The Education of the Blind, V. 10, n. 3 (Mar., 1961), pp. 82-84. Although the following articles do not relate to textbook design for partially seeing students, they do provide essential information on the subject of color and tonal contrasts between text or symbols and backgrounds upon which they are printed; Miles A. Tinker and Donald G. Patterson, "Studies of Typographical Factors Influencing Speed of Reading - VII, Variations in Color of Print and Background," Journal of Applied Psychology," V. 15 (1931) pp. 471-479; Miles A. Tinker, "The Effect of Color on Visual Apprehension and Perception," Genetic Psychology Monographs, V. 11 (1932), pp. 107-133; Katherine Preston, Howard P. Schwankl, and Miles A. Tinker, "The Effect of Variations in Color of Print and Background on Legibility," Journal of General Psychology, V. 16 (1932), pp. 459-461; F. C. Sumner, "Influence of Color on Legibility of Copy," Journal of Applied Psychology, V. 16 (1932), pp. 201-204; Sydney L. Smith, "Color Coding and Visual Search," Journal of Experimental Psychology, V. 64, n. 5 (Nov., 1962), pp. 434-440, R. B. Hackman and M. A. Tinker, "Effect of Variations of Print and Background Upon Eye Movements in Reading," American Journal of Optometry & American Academy of Optometry, V. 34, n. 7 (July, 1957), pp. 354-359.

Map Test Design and Use

Test Compilation. The design of the map test required a master map compilation of over 360 arrow symbols, all intersecting at different locations with the map boundaries, grid lines, and rivers and coast lines. No arrow was plotted to intersect more than one type of line symbol, and no point of intersection was used twice. No two arrows on the master arrow symbol compilation either touched, crossed or ran parallel with each other, and the minimum spacing between arrows was approximately 1 centimeter.

Arrows were distributed from the master compilation to the test maps in accordance with an arbitrary set of systematic rules. Ten (10) arrows from the master arrow compilation were selected for each of the 36 maps contained in the map test.[8] In order to facilitate selection of an even distribution of 10 arrows on each of the test map areas, the master compilation of arrow symbols was divided into three sections coinciding with the spatial arrangement of the other map base symbols, which appear as relatively low, medium and high density

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[8] Actually, 372 arrow symbol positions were compiled, since a practice map containing 12 arrow symbols was included in the map test booklets. Refer to Map Test Booklet, Volume 2, Appendix, "Map Test Systematic Compilation Sequence Matrix," columns indicating Number of Arrow Intersections with Rivers & Coastlines, Boundary Lines, Latitude and Longitude Lines. Note all additive combinations of 10 arrow intersections for 36 maps.

distributions. Symbol density means the amount of symbol clustering or loading per unit of map area. On observing the distribution of boundaries, grid lines, and rivers and coastlines on any one of the test maps in the Map Test Booklet, Volume 2 Appendix, the right third of the map appears to have a relatively low density of symbols, the central section has a medium density of symbols, and the left third of the map has a relatively high density of symbols. Thus, totals of 10 arrow symbols in additive combinations of 3-3-4, 3-4-3 and 4-3-3 were "spread" across low, medium and high symbol density sections of each of the test maps.

Since each test map has 10 arrow symbols, the allocation of the intersections of these symbols with the other three categories of line symbology (boundary lines, grid lines, and rivers and coastlines) is limited to a number of additive combinations or "additive rules of intersection," as well as an arbitrary stipulation that each test map must contain at least one arrow intersection for each of the three categories of map base symbols. Thus, no test map may contain more than 8 arrow intersections for any one category of map base symbol, so that the remaining 2 arrow intersections can be allocated to each of the other two categories of map base symbols. When a test map contains 8, 7, 6, 5, 4, 3, 2, or 1 arrow symbol intersection(s) for any single category of map base symbols, then the spread of such allocation of intersections is systematically distributed in high, medium and low density sections of the map (see Table 1). In cases

TABLE 1

COMPILATION TABLE OF SECTIONAL DISTRIBUTIONS OF ARROW SYMBOL INTERSECTIONS

Number of Arrow Intersections Allocated for Any Single Category of Map Base Symbols	MAP BASE SYMBOL DENSITY SECTIONS Allocation of Arrow Symbol Intersections per Map Section High Density	Medium Density	Low Density
1 *a	0	0	1
2 *b	0	1	1
3	1	1	1
4	1	1	2
5 *c	1	2	2
6	2	2	2
7 *d	2	2	3
8 *e	2	3	3

* Alternative high-medium-low distributions sometimes were used to improve legibility of intersections: (a) 0-1-0, 1-0-0; (b) 1-0-1, 1-1-0; (c) 2-2-1, 2-1-2; (d) 2-3-2, 3-2-2; (e) 3-3-2, 3-2-3

where only 1 arrow intersection is allocated to a density region of a map, the arrow intersection position is selected to be as close as possible to the map center side of the section.

The 36 test maps initially were compiled for the Map Test Booklet in a systematic order according to their specific test viewing distances, background characteristics and line-width dimensions. This compilation order is described in the Map Test Systematic Compilation Sequence Matrix on the third preface page of the Map Test Booklet, Volume 2, Appendix. All of the systematically arranged map test pages were assigned a random number from a Table of Random Numbers.[9] The map test pages were finally assembled in a random order in the Map Test Booklet, so as to decrease the chances of a biased subject response from the initial, systematic compilation arrangement. The random page order is described in the Map Test Random Viewing Sequence Matrix which appears on the same page of the Map Test Booklet referred to above. A practice test map (Random Number 00x) was inserted at the beginning of the random sequence of map test pages.

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[9]Herbert Arkin and Raymond R. Colton, Tables for Statisticians, Second Ed., New York: Barnes & Noble, Inc. (1963), pp. 158-161.

Test Controls and Procedures. The types of controls and procedures devised for the map test include rules of page sequencing, environmental illumination level, object (map) specifications, and subject/object (map) operational test procedures. These types of controls and procedures are described in the following paragraphs, as well as in the preface pages of the Map Test Booklet, Volume 2, Appendix.

In order to reduce possible test response error from peaks of fatigue when a number of subjects were given the map test simultaneously, a rotational sequencing of the random page order was developed and employed in all Map Test Booklets used for actual testing operations. Thirty-six (36) "operational booklets" were assembled in a key-ring loose-leaf fashion, with soft cardboard covers. The practice test map (Random Number 00x) was inserted as the first page in each booklet. The booklets were given code numbers from 1 to 36. Number 1 was assigned a page sequence identical to the one in the Map Test Booklet, Volume 2, Appendix. This sequence is described on the Map Test Random Viewing Sequence Matrix on the third preface page in this booklet. Each of the other operational test booklets (Number 2 through Number 36) were paginated according to a successive rotational numeric sequence; i.e., the first test map in Booklet Number 2 was the map designated Random Number 02x and the last test map was the map designated Random Number 01x, the first test map in Booklet Number 3

was the map designated Random Number 03x and the last test map was the map designated Random Number 02x, the first test map in Booklet Number 4 was the map designated Random Number 04x and the last test map was the map designated Random Number 03x, etc. Groups of subjects simultaneously tested numbered less than 12, and each subject was issued a test booklet with a code number at least several digits apart. The test director-monitor told groups of test subjects when to turn the page during the map test, and also that each individual would be working on a different page from all others in the group. The pages were not numbered, and test monitors closely checked to see that no more than one page was turned at a time.

Higher levels of illumination, usually, are necessary for partially seeing persons than for normally seeing people. A minimum lighting level of 50 footcandles has been recommended for sight-saving classrooms by several authorities. Also, it has been suggested that illumination levels as high as 100 footcandles or more might be beneficially used in such classrooms, since increases in visual acuity often may be achieved by increasing the level of light reflected from reading

materials, graphics and other objects.[10] All classrooms used for map testing in this experiment had nonglare illumination levels measuring between 30 and 50 footcandles. Lightmeter readings were taken in each classroom at a 14 inch (35.56 centimeters) reading distance from the practice test map which has a white background.

Object (map) viewing controls devised for the map test include the symbology, the area, the backgrounds and the dimensions of the symbols. These items are described in the two sections of the first part of this chapter. Tolerances for symbol width and length were maintained at plus or minus 0.001 inch or 0.025 millimeter. Line-width dimensions and backgrounds for each test map conform with the Map Test Random Viewing Sequence Matrix data (see Volume 2, Appendix, Line-Width and Background columns).

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[10] Winifred Hathaway, Education and Health of the Partially Seeing Child, Fourth Ed., New York: published for the National Society for the Prevention of Blindness, Inc. by Columbia Univ. Press (1959), pp. 90-92; Matthew Luckiesh and Frank K. Moss, Reading as a Visual Task, New York: D. Van Nostrand Co., Inc. (1942), pp. 46-50, 291-296; American Standard Practice for School Lighting, Publ. A-23 (1948), p. 36; John E. Kaufman, Ed., IES Lighting Handbook, 4th Ed., New York: Illuminating Engineering Society (1966), p. 11-18; Several subjects whose vision problem was diagnozed as albinism, achromatopsia and cataracts (having an opacity at the nodal point close to the lens), which results in severe discomfort and loss of visual acuity in bright light, were permitted to take the map test in specially darkened areas in the sight-saving classrooms.

Subject/object (map) operational procedures devised for the map test include regulation of the viewing time per test map, alignment of the viewing plane and control of the three viewing distances. Frequent reference to the Map Test Booklet will provide supplementary clarification of the information on subject-object spacing (viewing distance).

Pre-test trials of the map testing system indicated that a 3 minute interval should provide adequate time for subjects to scan, count and record the arrow symbols on one test map. Since the interval of time allocated for inspecting a map was not a prime control in obtaining subject responses, the 3 minute period was used to reduce the total time required for the entire map test. Replication of these tests could be carried out using greater or lesser periods for each map observation. Major factors influencing the time period used relate to fatigue, attention-span and learning rate. A test monitor announced to the subjects when to begin and when to stop inspecting each test map, and when to turn each page in the booklet. The 3 minute time periods were measured with an electronic photo-timer. A red light was connected to the timer to provide an easy visual indication to both the monitors and the subjects when the 3 minute testing periods were in effect. Several rest periods were permitted during the approximate $1\frac{1}{2}$ hours the map test required.

Alignment of the map test viewing plane and control of the three viewing distances was accomplished manually by the subjects through use of three straight, color coded spacing sticks measuring 7 (red), 14 (gold) and 21 (green) inches in length (17.78, 35.56 and 53.34 centimeters, respectively). Each test subject was given a set of these spacing sticks and instructed in their use. A star symbol, color coded to match one of the spacing sticks, was affixed to the bottom-center margin of each test map in accordance with the specifically assigned viewing distance characteristic of the particular map (see Map Test Random Viewing Sequence Matrix, Viewing Distance column in the Map Test Booklet, Volume 2, Appendix). Thus, the subjects selected the proper spacing stick to use with each test map. One end of the stick was held nearly perpendicular by the subject against his chin, and the other end was held at a right angle touching the colored star at the bottom-center of a test map, thus controlling the viewing distance and aligning the viewing angle between the subject and the test map. The spacing sticks ordinarily were held in the subject's left hand and aligned so that he was nearly perpendicular to the test map viewing plane. Since some of the spacing sticks were quite long, the subjects had to stand in order to properly use them. The map booklets were placed in a horizontal plane on standard classroom work tables which were about 30 inches high (about 20 inches high in elementary schools). After proper spacing and alignment adjustments for each map, test subjects

located, identified, counted and recorded the numbers of arrows intersecting with the other map symbols. Arrow counts were written in pencil on special answer sheets affixed to the right-hand edge of each test map. The map test questions on the answer sheets were printed in bold, 24 point typeset in order to facilitate readability. Test monitors checked closely to see that correct spacing sticks were being used in a properly aligned manner, and also to make sure that subjects attempted to count and write down their responses on the answer sheet for every test map.

Test Subjects. The 43 partially seeing students who participated as subjects in the map testing program had previously seen and used some form of outline map. The group of subjects had an age range between 8 and 52 years, but a majority were under 19 years of age (86 percent). Forty-nine (49) percent of the subjects were between the ages of 8 and 12, 37 percent between the ages of 13 and 19, and 14 percent were between the ages of 20 and 52 years old. A majority of the subjects were male (81 percent). Most of the subjects were right-handed (86 percent), and those that were not had no difficulty in performing the tasks of holding the spacing sticks properly and recording their answers on the answer sheets. All subjects were recruited from sight-saving classes in the public schools in the city of Seattle,

Washington, and nearby suburbs.[11] General statistics including age, sex, school grade, etc., and special information on visual acuity and medical diagnosis were recorded for each test subject on a special record form (see Figure 4).

The visual acuity deficiencies of the entire test subject population may be categorically described as ranging on the Snellen rating scale between moderate, severe and very severe levels in the better eye after optical correction.[12] Fifty-one (51) percent of the test subjects had moderate visual acuity handicaps with Snellen scale ratings between 20/70 and 20/200, 31 percent had severe handicaps with ratings of less than 20/200 and 18 percent had very severe handicaps with ratings of less than 20/200 and extreme behavioral (muscular) or visual impairments. The etiology (medical diagnosis) of the test subject's visual deficiencies are listed on Table 2 as

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[11] Schools participating in this project are noted in the Preface.

[12] Descriptive categories of degrees of partial sight are presented in Barbara D. Bateman, "Reading and Psycholinguistic Processes of Partially Seeing Children," CEC Research Monograph, No. 5, Washington: The Council for Exceptional Children, National Education Association (1963), pp. 9-14.

MAP TEST RECORD FOR PARTIALLY SEEING STUDENT SUBJECT
Cartography Laboratories Department of Geography
University of Washington Seattle, Washington

NAME OF PUPIL	CODE NO.	AGE
SCHOOL	GRADE	SEX
ADDRESS OF SCHOOL	RIGHT-HANDED	LEFT-HANDED
INSTRUCTOR/SUPERVISOR CONTACTS		TELEPHONE

DATE OF TESTING 1._____ TIME OF TESTING 1._____

2._____ 2._____

VISUAL ACUITY WITH PRESENT GLASSES	Right Eye	Left Eye	Both Eyes
Snellen Rating:			
Near Vision:			
Type of Refractive:			
Other Ocular Defect or Disease:			
Etiology:			

Remarks & Test Summary:

Figure 4. Subject Record Form.

TABLE 2

OCULAR DEFECTS OF TEST SUBJECTS
(including secondary defects)

1. Retrolental Fibroplasia
2. Aniridia
3. Myopia, Esotropia, Nystagmus, Optic Atrophy
4. Cataract
5. Cataract, Nystagmus, Microphthalmos
6. Retrolental Fibroplasia, Glaucoma
7. Hyperopia, Optic Atrophy
8. Albinism, Nystagmus
9. Nystagmus
10. Myopia
11. Myopia, Brain Tumor
12. Istigma, Nystagmus, Myopia
13. Myopia
14. Myopia, Astigmatism
15. Myopia, Retinitis Pigmentosa
16. Myopia
17. Myopia
18. Myopia, Astigmatism
19. Subluxated Lens, Marfan[s Syndrome, Color Blind Tendency
20. Nystagmus, Optic Atrophy
21. Nystagmus, Esotropia
22. Nystagmus, Optic Atrophy
23. Estoropia, Nystagmus, Myopia, Jones Reflex
24. Conunctivitus, Stevens-Johnson Syndrome
25. Esotropia, Myopia, Retinopathy
26. Nystagmus, Myopia
27. Nystagmus, Myopia
28. Retrolental Fibroplasia, Nystagmus
29. Myopia
30. Cataract, Retinitis, Diabetes
31. Cataract
32. Cataract, Iritis
33. Nystagmus, Amblyopia
34. Retinitis, Retinitis Pigmentosa
35. Retinopathy, Retinal Detachment, Diabetes
36. Albinism
37. Aniridia, Glaucoma
38. Myopia, Cataract, Retinitis Pigmentosa
39. Optic Atrophy
40. Optic Atrophy, Hyperopia, Extropia
41. Retrolental Fibroplasia, Cerebral Palsy
42. Nystagmus, Albinism
43. Nystagmus

Etiology may be incomplete or improperly diagnosed in some cases. Multiple defects for individual subjects are listed in order of severity, the worst one first. The numeric sequence of the above listing only relates to the order of subject interview.

supplementary data only, and an ophthalmic reference or medical dictionary should be consulted for descriptive definitions as well as other diagnosis of partial sight.[13]

Map Test Production

Photomechanical Assembly and Reproduction. The initial stage of assembly of the test map base consisted of the design and compilation of an outline map of selected geographical elements of the State of Washington (refer to Figure 5 throughout the following text). This compilation, containing geographical grid lines, political boundaries, and selected rivers and coastlines, was developed by simplifying a tracing of a standard school outline map of the State of Washington.[14]

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[13]Note that map test responses are analyzed in Chapter III for the test population as an entire group, representing a typical urban sampling. This study does not attempt to analyze the map test responses relating to individual or group attributes such as separate categories of visual acuity, ocular medical diagnosis types, age ranges, school grade level, sex, etc. A much larger subject population should be used for such particular analysis.

The opthalmic terms listed in Table 2 are defined in reference books such as Conrad Berens, M.D., Ed., The Eye and Its Diseases, Philadelphia: W. B. Saunders Co. (1956), 1254 pp.; Charles A. Perera, M.D., Ed., May's Manual of Diseases of the Eye, Baltimore: Williams and Wilkins Co. (1949), 512 pp.; and W. A. Newman Dorland, M.D., The American Illustrated Medical Dictionary, 24th Ed., Philadelphia: W. B. Saunders Co. (1965), 1724 pp.

[14]Photomechanical operations are those which utilize photographic processes in conjunction with manually operated drafting and reproduction tools. The outline map employed in the compilation process is cited in the first footnote at the beginning of this chapter.

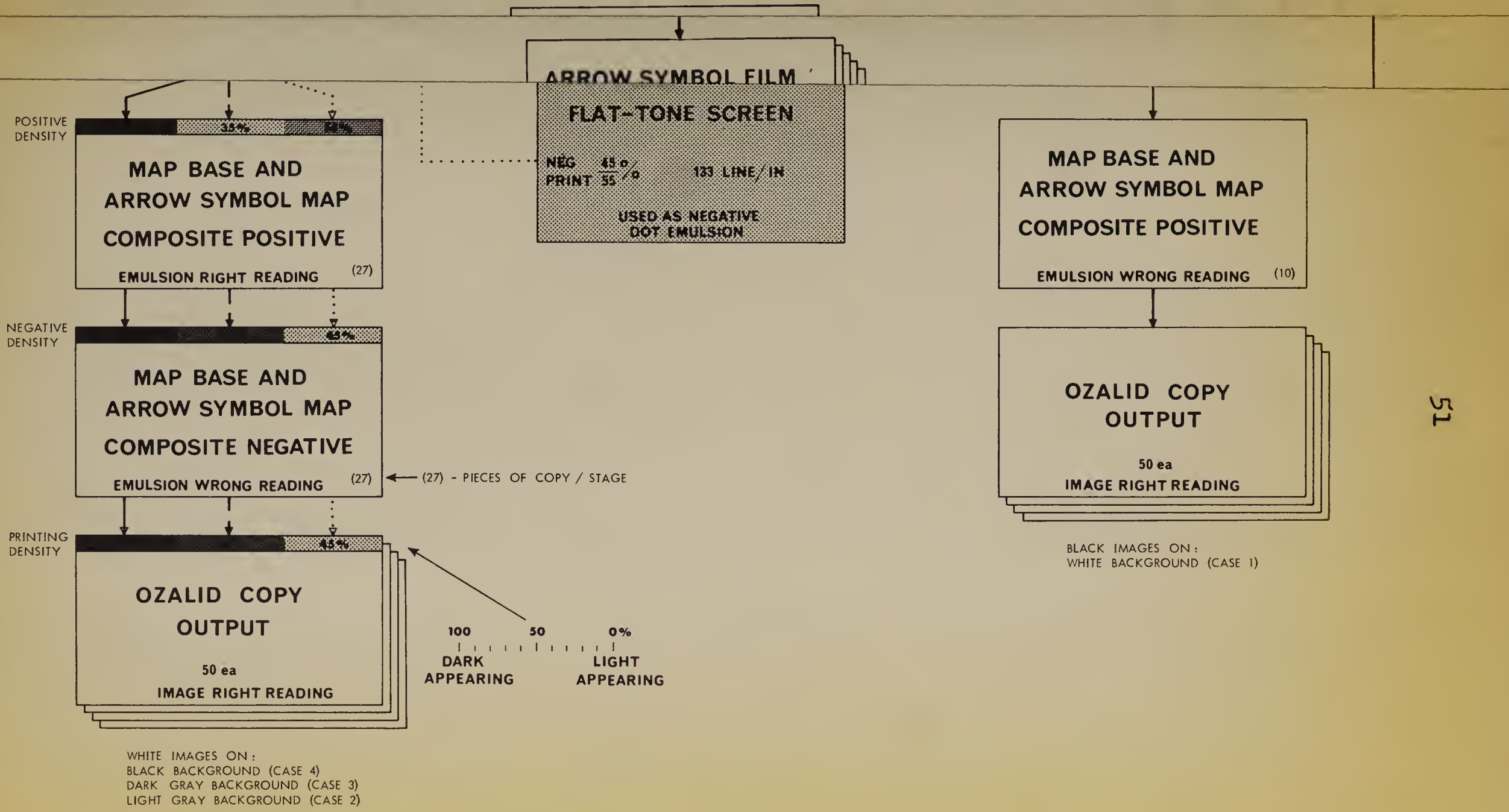

FIGURE 5. MAP PRODUCTION FLOW CHART

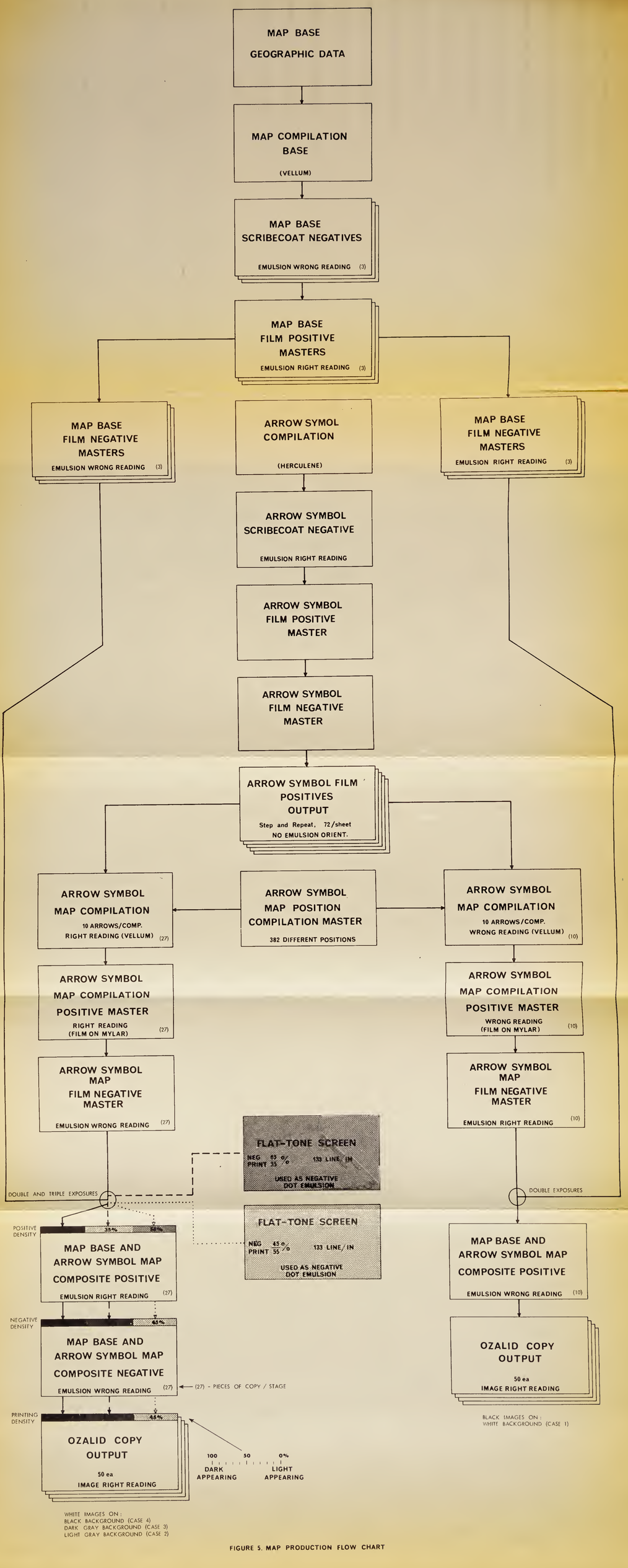

FIGURE 5. MAP PRODUCTION FLOW CHART

Three master negatives were scribed of the compilation images at three different line-widths onto 11 inch by 15 inch sheets of dimensionally stable mylar Scribe Coat material.[15] Identical map base negatives containing the data elements were scribed at line-widths of 0.015 inch (0.381 millimeter), 0.030 inch (0.762 millimeter), and 0.045 inch (1.143 millimeters), all at a dimensional tolerance of plus or minus 0.001 inch (0.025 millimeter). Three right reading master film positives were produced from the Scribe Coat negatives, using a photographic contact printing process.[16] Next, sets of right and wrong reading master film negatives were produced by contact printing from the film positives. These film negatives were used at a later multiple-exposure, photographic stage of map production, where specific patterns of arrow symbols were superimposed upon map base images in order to make 37 different maps. This procedure may be identified

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[15] Scribing is a drafting-engraving process by which line symbols of precise and uniform dimension are engraved onto specially coated, dimensionally stable glass or plastic surfaces. Negative images are usually produced wherever the surface coating has been removed by a special precision engraving tool. See Lionel C. Moore, Cartographic Scribing Materials, Instruments and Techniques, Second Edition, Tech. Publ. No. 3, Washington: American Congress on Surveying and Mapping (Mar., 1968), 20 pp.

[16] A right reading image is one which appears in its normal configuration and orientation on the emulsion-side of a film positive or negative. A wrong reading image appears reversed in orientation on the emulsion-side of a film positive or negative. Contact printing involves exposure of light through a stencil (a film positive or negative) to create a same size image.

with the "multiple-use concept" in map production, where complete or partial separation of map elements (symbols or images) is done at the drawing stage and selectively reassembled at subsequent production stages.[17]

Arrow symbol images were compiled and scribed on a separate sheet of Scribe Coat base material at the same three line-width dimensions as specified for the map base symbology. A master film positive and negative subsequently were produced by the photographic contact printing process. Six film positive prints were made from the master negative. These prints each contained 72 arrow symbols drawn at the three line-widths specified above. Such a procedure is called the "step and repeat" photographic process. The arrow symbol images on the film positives were cut out and selectively used in the production of 37 different master arrow symbol map arrays. These arrays were constructed in positive form on 11 inch by 15 inch sheets of transparent mylar film, with the cut out film arrow images affixed with rubber cement. The arrow symbols were positioned in accordance with 37 predesigned arrow symbol map position compilations. Master right and wrong reading negatives of the arrow symbol map arrays were subsequently produced by the photographic contact printing process.

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[17] John C. Sherman and Waldo R. Tobler, "The Multiple Use Concept in Cartography," The Professional Geographer, V. 9, n. 5 (Sept., 1957), pp. 5-7.

The master film negatives of the arrow symbol map arrays and the map base both were selectively combined into composite film positives by means of a double-exposure contact process.[18] In some cases during this stage of production, light and dark gray tones were produced on the map base background by means of 65 percent and 45 percent, 133 lines per inch flat-tone photographic contact screens.[19] The making of composite positive prints constituted a final stage of photomechanical map assembly, with respect to the production of test maps having a white background. Composite negatives also were made from some of the composite positive prints by means of contact printing. These composite negatives constituted a final stage of photomechanical assembly, with respect to the production of test maps having black and light and dark gray tonal backgrounds.

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[18] A double-exposure, photographic contact printing process is an operation whereby selected images, usually in separate negative form, are successively exposed onto a single sheet of unexposed film which is then developed and processed with all of its multiple-image contents. The selection of image combinations of arrow symbols and map bases was carried out in accordance with the Map Test Systematic Compilation Sequence Matrrix (Volume 2, Appendix).

[19] Triple-exposures were necessary whenever the contact screens were used. A photographic flat-tone contact screen used in the contact printing process is a plastic photographic film material containing a uniform dot, line or other grain pattern. Upon contact printing exposure, the screen creates a specific image pattern or tonal background onto the film being exposed.

The Ozalid reproduction process was used to produce multiple copies of the test maps in their final form.[20] As indicated in Figure 5, in order to produce a map with a white background, the Ozalid process requires a positive black image on a transparent (or translucent) background. In order to produce maps having black and gray tonal backgrounds, the Ozalid process requires a negative image with an opaque or screened background. Advantages of the Ozalid process include low cost and fast output for small production quantities, good dimensional stability especially when printing is done on card stock base material, and the image quality is good.

There are a number of disadvantages to use of the Ozalid process which must be noted. Although the image quality is good, the background quality is not as good as that obtainable from an offset lithographic printing process, especially in cases of tonally screened maps. The gray tonal quality of the Ozalid prints that were produced is more than adequate, however, for partially seeing persons who cannot discriminate the differences in tonal quality between an Ozalid print and those made by other processes of map reproduction. Several problems occurred during the Ozalid printing of the test maps having

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[20] This process, also known as "diazo printing," is described in Joe W. Coffman, Technology of the Diazotype Processes, Holyoke, Massachusetts: Technifax Corp. (1960), 9 pp.

gray tonal backgrounds. It was discovered that the tonal backgrounds would be reproduced in a very uneven, unacceptable manner unless the Ozalid base material was loaded into the Ozalid machine with the grain of the Ozalid emulsion aligned perpendicular to the machine paper rollers. Also, the exact same tone of gray could not be reproduced when utilizing Ozalid base material from two different packages. It seems that there are inconsistencies in the quality control (from package to package) of the composition and uniformity of chemical coating on even the highest quality Ozalid base material. A somewhat acceptable compensation for these inconsistencies was made by critically adjusting the Ozalid machine exposure control and making proof comparison prints whenever starting a new package of material. Much waste occurred at each change of package. Another problem was that small black specks or streaks often were added to the map images because of blemishes in the Ozalid base material and from dust contamination of the light exposure system and the paper rollers in the Ozalid machine. The manual loading requirement of the machine tends to slow down the production operation, especially on runs of more than 10 copies of a single map. Fifty (50) copies of each of the 37 test maps were made, totaling 1857 copies in all. Over 2800 sheets of Ozalid material were used to produce the 1857 maps required for the test booklets. Occasionally, the Ozalid machine jammed and destroyed a composite negative or positive that served as a reproduction master

image. The Ozalid operation does not have automatic collating, trimming and binding devices like those which are commonly used with the offset printing process. Thus, manual collating, trimming and binding (3-hole hand punching with key ring fasteners) operations added much time to the final map test production. The final prints with black and gray tonal backgrounds had a tendency to fade after about 30 days of use, apparently due to continued chemical change of the emulsion which is affected by strong light and air. Needless to say, the use of an offset lithographic printing process would have eliminated many of these problems, and saved many extra man-days of labor. The restricted operating budget of this project forced the selection of less costly Ozalid printing of the test maps.

Equipment and Materials. An extensive array of equipment and materials was required for the production of the map test booklets and for testing operations. The major categories of items employed include (A) drafting and scribing tools and materials, (B) precision measuring instruments, (C) photographic equipment and materials, (D) map test control apparatus, (E) answer sheet forms and (F) booklet page, binding and cover materials. The most important items in these categories are listed in the Appendix of Equipment and Materials at the end of Volume 1. This appendix also contains notations on the manufacturer and the particular function of the equipment and materials listed.

Conclusion

The formulation of a map testing system, together with the creation of map test materials, as presented in this chapter, provided the means by which subject responses could be acquired. It is obvious that these responses (test results) had to be collected and analyzed in order to obtain measures of the readability of test maps with differing design characteristics. The following chapter contains a presentation of test data, analytical procedures and the results of the analysis of map test responses.

CHAPTER III

ANALYSIS OF MAP TEST RESULTS

The analysis of the map test results, utilizing selected statistical methods, provides a means of determining the validity of the hypothesis, involving irradiation effects created by image-to-background contrast relationships. An attempt is made in this section of the study to analyze subject response trends which indicate differences in readability of the different test maps. The analysis is by no means conclusive, but it does provide a measure of evidence indicating that certain of the map designs that were employed have readability advantages. Since the subject population was small, this analysis was limited to descriptive rank and mean trend interpretations.

This chapter is divided into four parts. The initial section contains a description of the test scoring technique used, and the second, the statistical methods employed in the analysis. A third section contains: (A) 36 graphic tables of map/subject test score data; (B) a tabular summary of map score rank-order, accumulated point scores per map, and mean score values for each map; and (C) 9 graphic tables containing mean and smoothed-mean score values arrayed as suggested mean and smoothed-mean trend lines. The fourth section of this chapter contains a summary and statistical interpetation of the tabular test score data and the graphic trend lines.

Scoring Method

Before analyzing any of the map test subject response data, special attention was given to the possibility of a high guessing effect biasing score values. In order to check this possibility, maps of potentially difficult, medium and easy readability were selected and scored in three different ways for the entire test population (43 subjects). Trial scoring methods included: (A) giving a subject full or partial point credit for each question (10 points per map, maximum, for all three questions) - no penalty was added if a numeric entry for a question on the answer sheet was greater than it was supposed to be; (B) full or partial point credit for each question - but if an entry for a question on the answer sheet was greater than twice the actual value for that question, zero point credit was given; (C) full or partial point credit for each question - but if an entry for a question on the answer sheet was greater than the actual value for that question, then the amount of the entry over and above the actual value of the question was subtracted from the total number of points accrued from correct

answers to all three questions for the map.[1] Mean scores for all three methods for the three sample maps checked, showed less than one point of variation between the different trial scoring methods employed. Since the penalty-weighted scoring methods produced little difference in mean scores as compared to the mean scores obtained using the non-penalty scoring method, it was concluded that guessing was not highly significant. Hence, scoring method A was chosen.

Statistical Methods

Rank Order Method. The first step in analyzing map test subject responses to viewing distance, background and line-weight factors was to transcribe in systematic order the map test answer sheet score data to "tally sheets" for each of the 36 test maps (see Tables 1-36). Mean score values $\overline{X}$ and sum total points ΣfX were calculated for

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[1] Note that the penalty scoring methods B and C check for over-guessing, i.e., entries greater than the actual values for given questions. In all three trial scoring methods, partial point credit was allocated for entries under-guessed or less than actual values for given questions. The regularity of the pattern of numeric entries on the answer sheets, with respect to answers which were less than the actual values for questions, indicates that the test subjects were responding normally to the variable test factor cases, rather than "systematically" under-guessing. For reference on "Factors Influencing Test Reliability," see David A. Payne and Robert F. McMorris, Educational and Psychological Measurement, Waltham, Mass.: Blaisdell Publ. Co. (1967), pp. 46-54.

each map. Next these map data were tabulated in rank-order from highest to lowest point score and mean score values (see Table 37). Specific response trends were immediately apparent by direct inspection of individual map readability rankings and corresponding test scores and map characteristics. These rank-order observations are summarized in the last part of this chapter.

Mean Graphic Trend Method. The second step in analyzing map test subject responses to viewing distance, background and line-width characteristics (variable test factors) was to graphically array the mean map test score values (see Tables 38-43). By arraying the mean map test score values (from Table 37) according to individual cases of one test factor sequenced in a varied (V) manner, e.g., 123/123/123/123/etc., as in the Line-Width row of Table 38; and then by arraying on the same table a corresponding set of test factor cases in a semi-constant (SK) fashion, e.g., 111/222/333/444/etc., as in the Background row of Table 38; and finally, by arraying on the same table a third corresponding set of test factor cases assembled in a constant (K) fashion, e.g., 111/111/111/111/etc., as in the Viewing Distance row of Table 38, resulting mean map readability trend lines as shown on the graph section of this table were established. In this way the table shows the relationships between the three simultaneous arrangements of test factor cases. This method simultaneously arranges the three interacting factors that cannot be independently

separated in terms of their individual effects.[2] One should note, however, that in the application referred to this method of arrangement of interacting test factor cases does permit a limited detection of effects of varied (V) test factor cases upon their corresponding semi-constant (SK) and constant (K) sets of cases. Five tabular rearrangements (Tables 39-43, Sequences B, C, D, E, F) of the original systematic test order sequence of test factor cases (Table 38, Sequence A) were developed in order to produce all possible combinations of mean map readability trend lines shown on the graph sections of these tables. A summary of trend attributes suggested on these graphs is included in the last part of this chapter.

Smoothed, Mean Graphic Trend Method. A third step of analysis was to employ a statistical smoothing method upon the first set of mean data (graphic values of Tables 38-43) in order to simplify and reduce the number of trend lines.[3] Average values of the mean graphic

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[2]William S. Ray, An Introduction to Experimental Design, New York: The Macmillan Co. (1960), pp. 171-174; Oscar Kempthorne, The Design and Analysis of Experiments, New York: John Wiley & Sons, Inc. (1952), pp. 252-263; A. W. Wortham and T. E. Smith, Practical Statistics in Experimental Design, Columbus, Ohio: Charles E. Merrill Books, Inc. (1959), pp. 85-102. Cases are specified variations of a test factor or test variable, e.g., Line-Width Case 1 (LW 1) measures 0.015 inches.

[3]Herbert Arkin and Raymond R. Colton, Statistical Methods, Fourth Ed., Revised, New York: Barnes & Noble, Inc. (1959, 1961), pp. 46-49; Murray R. Spiegel, Theory and Problems of Statistics, New York: Schaum Publishing Co. (1961), pp. 285-289.

values of the test factor cases in Tables 38-43 were calculated for the sets of three cases (Sequences A, C, D, E) and sets of four cases (Sequences B, F). These average-mean or "smoothed-mean" test score values are summarized on Table 44. Also listed on this table are a second set of data, the smoothed-mean values of the smoothed-mean test scores. The use of these two sets of data will be explained in the following paragraphs.

Smoothed mean trend lines produced from the smoothed-mean test score values were plotted on the graph sections of Tables 45-47. Using the first smoothed-mean data from Table 44, pairs of smoothed-mean trend lines were plotted on the graphs according to respective semi-constant (SK) sets of test factor cases (e.g., see Table 45, Background and Line-Width Cases). Note that in order to produce all possible combinations of smoothed-mean trend lines, the test factor cases on Tables 45-47 are assembled in semi-constant sets corresponding to tabular sequence arrangements A, B, C, D, E, F, as on Tables 38-43. The corresponding varied (V) test factor cases have been deleted from Tables 45-47. This deletion of varied (V) test factor cases was done because of their reduced significance due to the operation of smoothing (or averaging) of the individual case variations of the original sets of three or four test factor cases. By including, on one graphic display, <u>two</u> sets of semi-constant (SK) test factor cases (e.g., Table 48, Background Cases - Sequence A, and Line-Width

Cases - Sequence B), mutually related to one set of constant (K) test factor cases (e.g., Table 48, Viewing Distance Cases common to both sequences A and B), pairs of smoothed-mean trend lines corresponding to their respective sequences of test factor cases were plotted in a superimposed manner. This technique permits multiple graphic observation of pairs of suggested smoothed-mean trends, as well as enabling the detection of peak smoothed-mean map readability combinations of test factor cases (at points on the graphs where the trend lines cross one another).[4] For example, on Table 45, for Viewing Distance Case 1, the optimum suggested combination of Background and Line-Width Cases might be 4 and 3, respectively. A summary of suggested smoothed-mean trends and optimum smoothed-mean map readability combinations of test factor cases is included in the last part of this chapter.

Secondary, smoothed-mean trend lines produced from the smoothed-mean test scores (see Table 44) also are depicted on the graph sections of Tables 45-47. These trend lines were plotted according to their corresponding set of test factor cases arranged on each table in a constant (K) fashion (e.g., see graph on Table 45,

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[4]The particular order of map sequences (A, B, C, D, E, F) was especially developed and used in order to permit the graphic detection of interactions of trend lines and their respective suggested map test factor characteristics.

Viewing Distance Cases mutually common to test factor case sequences A/B). The trend line for the Viewing Distance Cases on Table 45 suggests a general decrease in map readability from Viewing Distance Case 1 to Case 3. The trends suggested by each of the secondary, smoothed-mean trend lines on Tables 45-47 also are summarized in the final section of this chapter.

Statistical Tests. Several standard statistical tests were performed on the mean score subject response data in order to further verify or nullify the tentative conclusions developed through the analysis of the trend graphs. A difference-of-means test was carried out to determine, as indicated on the trend graphs, that certain maps with alternate design characteristics had significant differences in readability. A multiple regression analysis of all mean test response data was performed in order to determine the relative importance of the test factor cases (e.g., BK 1, 2, 3, 4) on map readability (test score). The interpretations of the results of these statistical tests are found in the concluding section of this chapter.

GRAPHIC AND TABULAR DATA

SAMPLE FORMAT PAGE

TABLE 0

[Explaining Map Score Entries on the following 36 pages of Tabular Data--Tables 1 to 36]

[Systematic Test Compilation No.]

RAW SCORE TALLY SHEET - MAP NUMBER 01/15X ← [Random Test Order No.]

~~Viewing Distance~~ 1 - {1 = 7", 2 = 14", 3 = 21"}
Background 1 - {1 = White, 2 = Light Gray, 3 = Dark Gray, 4 = Black}
Line-Weight 1 - {1 = 0.015", 2 = 0.030", 3 = 0.045"}

[Mean Test Score for 43 Subjects]

$\overline{X} = 6.98$

[Score for Subject 14 Using Booklet 14]

[Score for Subject 41 Using Booklet 14]

[Sum of Test Score Points for 43 Test Subjects]

$\sum fx = 300$

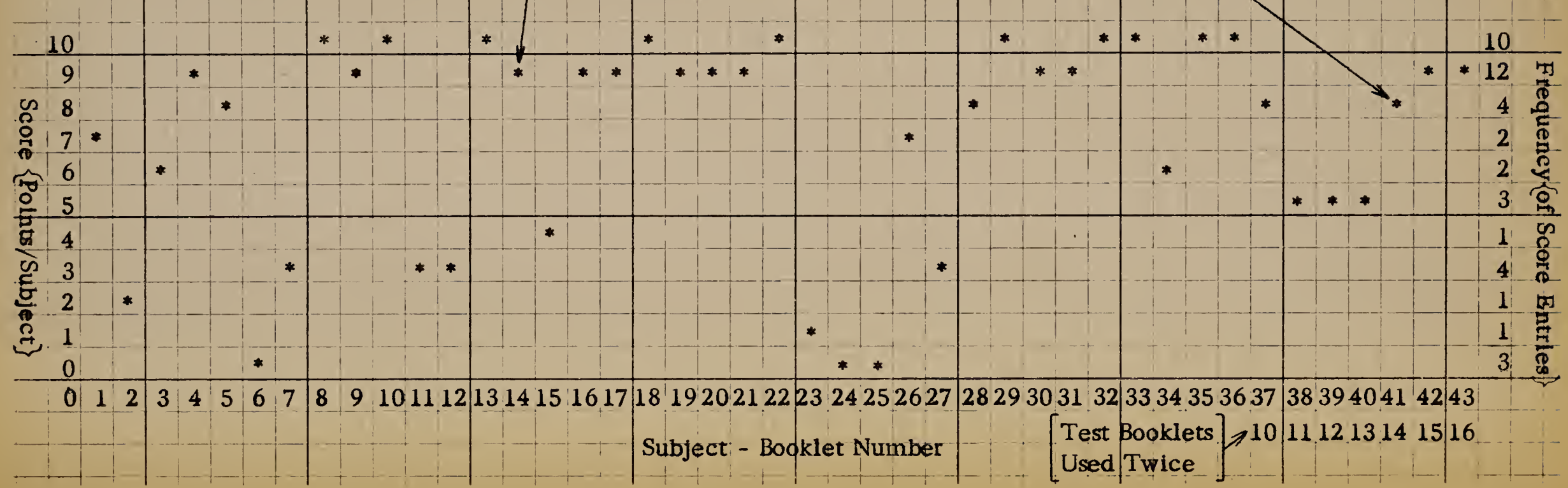


TABLE 1

RAW SCORE TALLY SHEET - MAP NUMBER 01/15X

Viewing Distance — 1
Background — 1
Line-Weight — 1

$\overline{X}$ = 6.98 $\sum fx$ = 300

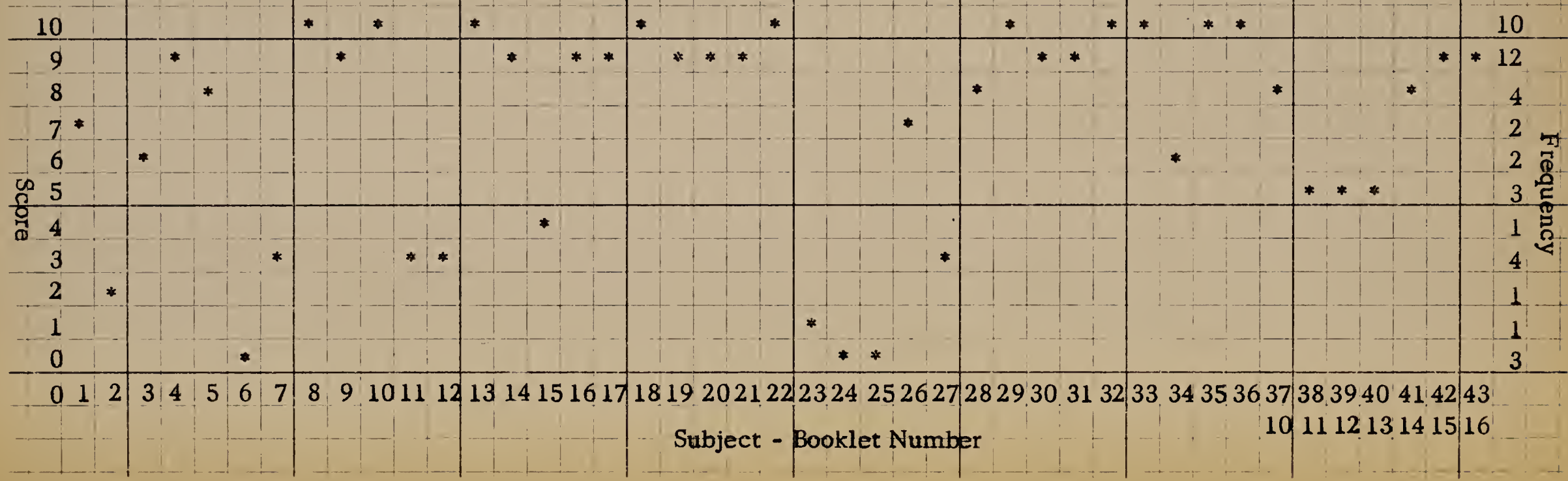


TABLE 2

RAW SCORE TALLY SHEET - MAP NUMBER 02/31X

Viewing Distance	1
Background	1
Line-Weight	2

$\bar{X} = 8.42$ $\sum fx = 362$

Score	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	Frequency
10		*				*					*			*					*	*	*	*	*					*	*	*	*	*			*	*							*	18
9													*				*					*	*			*	*												*			*	*	8
8								*		*					*	*									*				*						*				*	*				9
7																		*						*																	*				3
6																												*																	1
5				*								*																																	2
4																																													0
3																																													0
2																																													0
1		*																																											1
0							*																																						1
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
																																						10	11	12	13	14	15	16	

Subject - Booklet Number

TABLE 3

RAW SCORE TALLY SHEET - MAP NUMBER 03/36X

Viewing Distance	1
Background	1
Line-Weight	3

$\overline{X} = 8.19$ $\sum fx = 352$

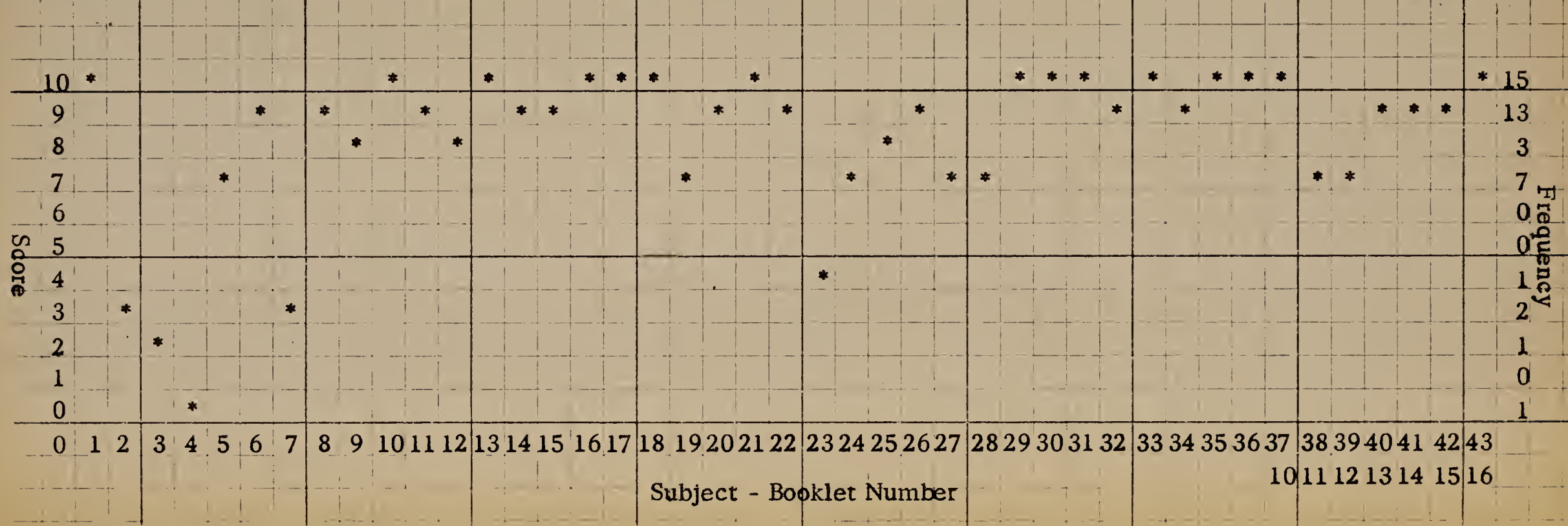


TABLE 4

RAW SCORE TALLY SHEET - MAP NUMBER 04/09X

Viewing Distance 1
Background 2
Line-Weight 1

$\bar{X} = 8.23$ $\sum fx = 354$

Score	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	Frequency
10		* *	* * *	* * *		*	* * * * *	* * *	* * *	*	20
9					* * * * *	*	*	*			8
8	*	*	*	*				*	*		5
7			*	*							2
6						*			*		2
5						*					1
4			*								2
3						*					1
2											0
1											0
0	*	*									2
	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	
					Subject - Booklet Number			10	11 12 13 14 15	16	

TABLE 5

RAW SCORE TALLY SHEET - MAP NUMBER 05/35X

Viewing Distance 1
Background 2
Line-Weight 2

$\overline{X} = 7.93$ $\sum fx = 341$

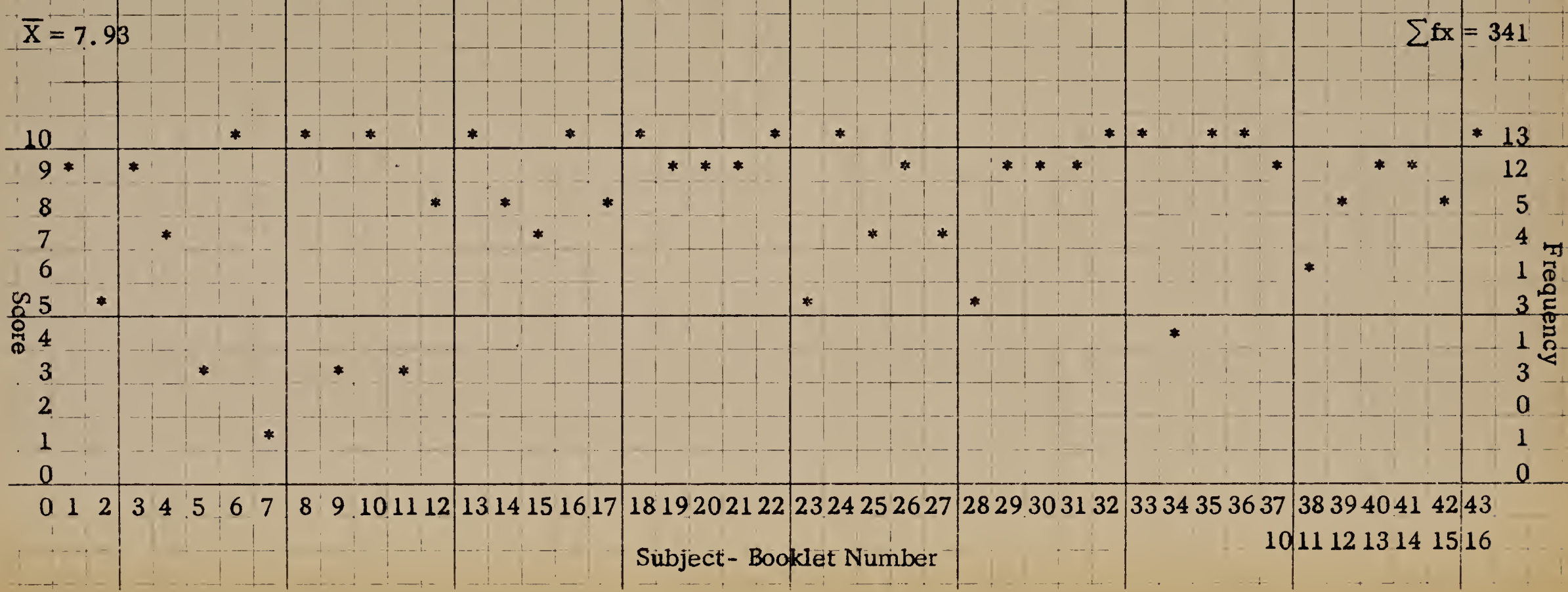


TABLE 6

RAW SCORE TALLY SHEET - MAP NUMBER 06/04X

Viewing Distance 1
Background 2
Line-Weight 3

$\overline{X} = 7.74$ $\sum fx = 333$

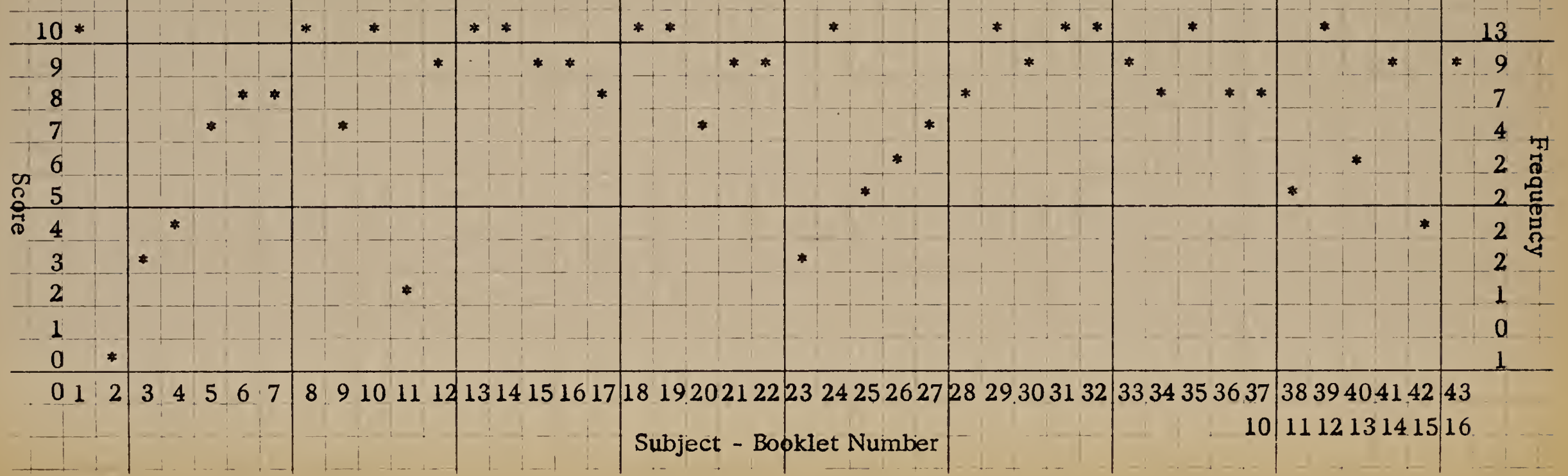


TABLE 7

RAW SCORE TALLY SHEET - MAP NUMBER 07/24X

Viewing Distance 1
Background 3
Line-Weight 1

$\overline{X} = 7.21$ $\sum fx = 310$

Score	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	Frequency
10		* *	*	* *	*		* * * * *	* *	*		13
9			* * *	* *	*			*		*	8
8	*							*	*		3
7		*				*			*		3
6					* *	*		*			4
5		*				*			*		3
4			*						*		2
3				*	*	* *	*				5
2											0
1	*										1
0		*									1
	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	
					Subject - Booklet Number			10	11 12 13 14 15	16	

TABLE 8

RAW SCORE TALLY SHEET - MAP NUMBER 08/02X

Viewing Distance	1
Background	3
Line-Weight	2

$\overline{X} = 8.26$ $\quad\quad$ $\sum fx = 355$

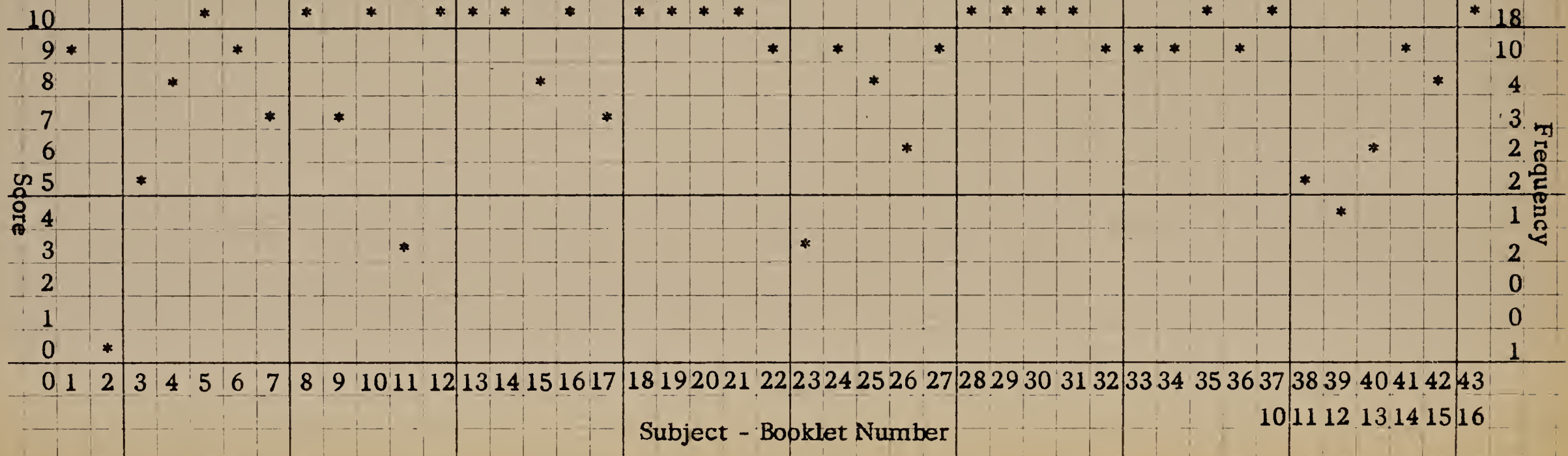


TABLE 9

RAW SCORE TALLY SHEET - MAP NUMBER 09/16X

Viewing Distance	1
Background	3
Line-Weight	3

$\bar{X} = 8.28$ $\sum fx = 356$

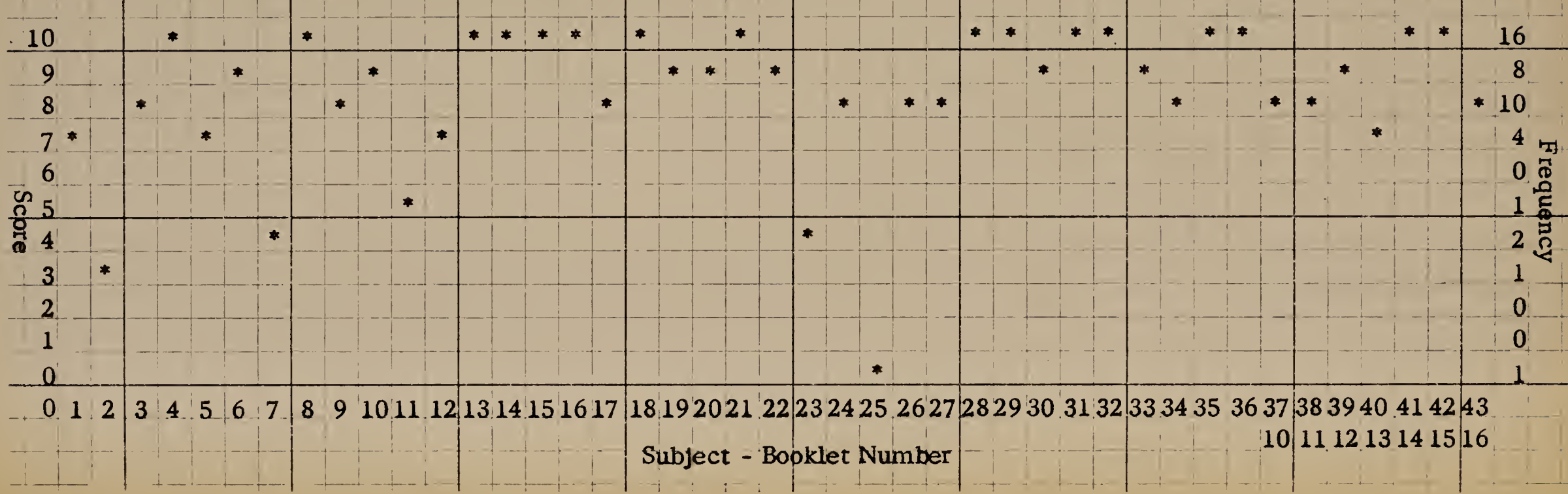


TABLE 10

RAW SCORE TALLY SHEET - MAP NUMBER 10/32X

Viewing Distance — 1
Background — 4
~~Line-Weight~~ — 1

$\overline{X} = 8.39$

$\sum fx = 361$

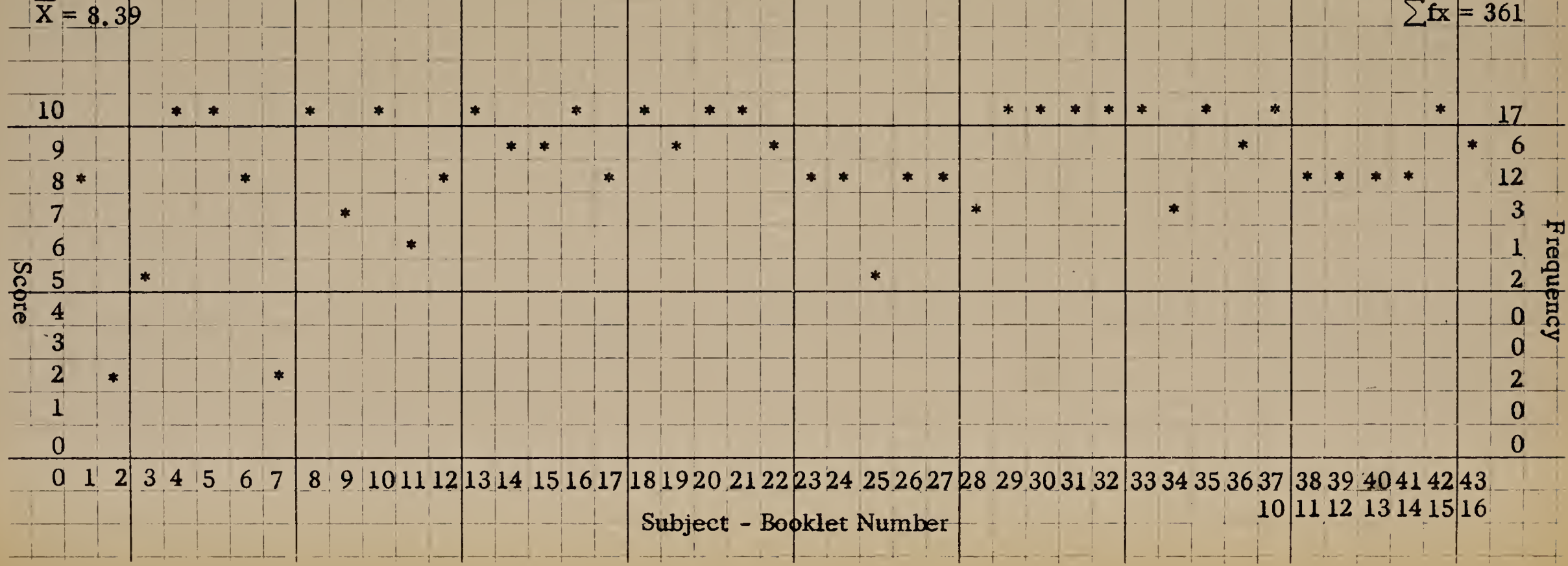


TABLE 11

RAW SCORE TALLY SHEET - MAP NUMBER 11/30X

Viewing Distance 1
Background 4
Line-Weight 2

$\bar{X}$ = 8.53 $\sum fx$ = 367

Score	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	Frequency
10					*	*			*	*	*			*	*	*	*		*		*					*			*		*	*		*									*	*	19
9	*												*							*		*			*										*		*	*							8
8																		*					*	*				*											*	*	*				6
7												*											*			*						*										*			5
6																																														0
5		*		*				*																				*																	4
4																																														0
3																																														0
2							*																																							1
1																																														0
0																																														0
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
																																						10	11	12	13	14	15	16	

Subject - Booklet Number

TABLE 12

RAW SCORE TALLY SHEET - MAP NUMBER 12/01X

Viewing Distance 1
Background 4
Line-Weight 3

$\overline{X}$ = 8.33 $\sum fx$ = 358

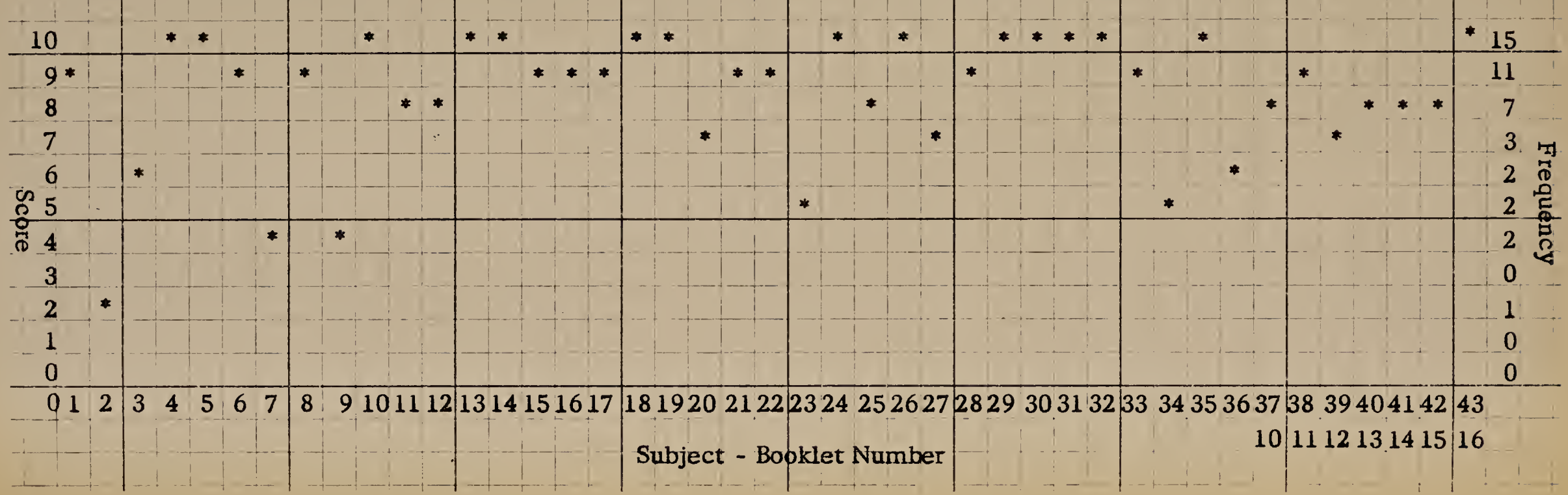

Score
Frequency
10 * * *

TABLE 13

RAW SCORE TALLY SHEET - MAP NUMBER 13/33X

Viewing Distance 2
Background 1
Line-Weight 1

$\bar{X}$ = 7.23 $\sum fx$ = 311

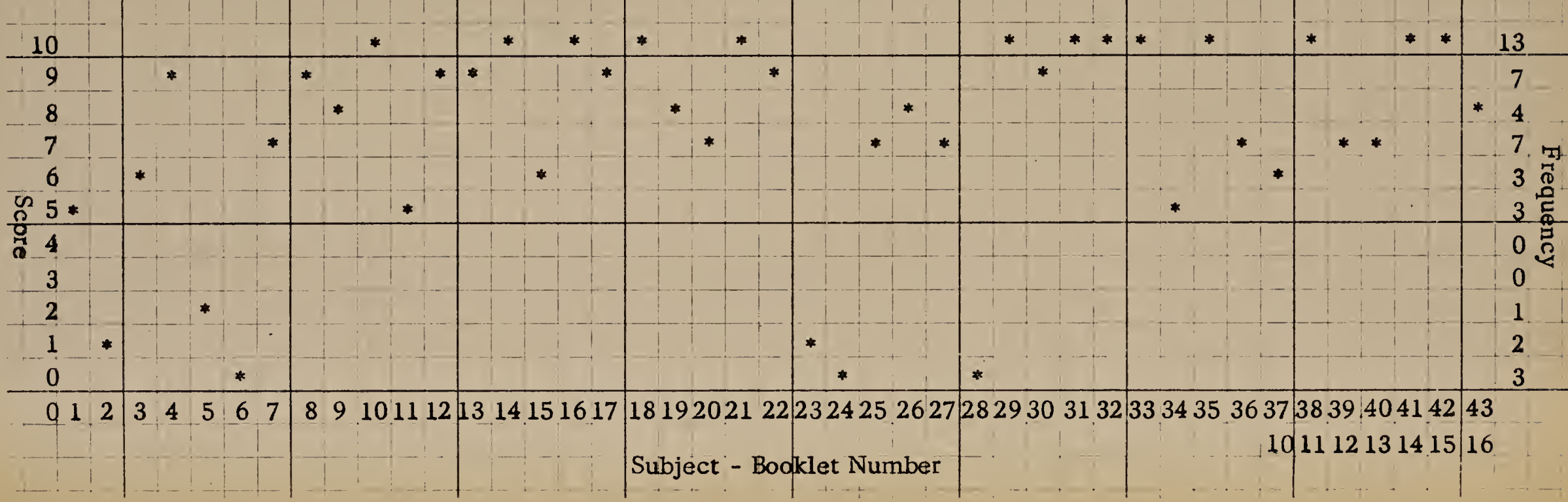


TABLE 14

RAW SCORE TALLY SHEET - MAP NUMBER 14/03X

Viewing Distance	2
Background	1
Line-Weight	2

$\overline{X} = 7.26$ $\sum fx = 312$

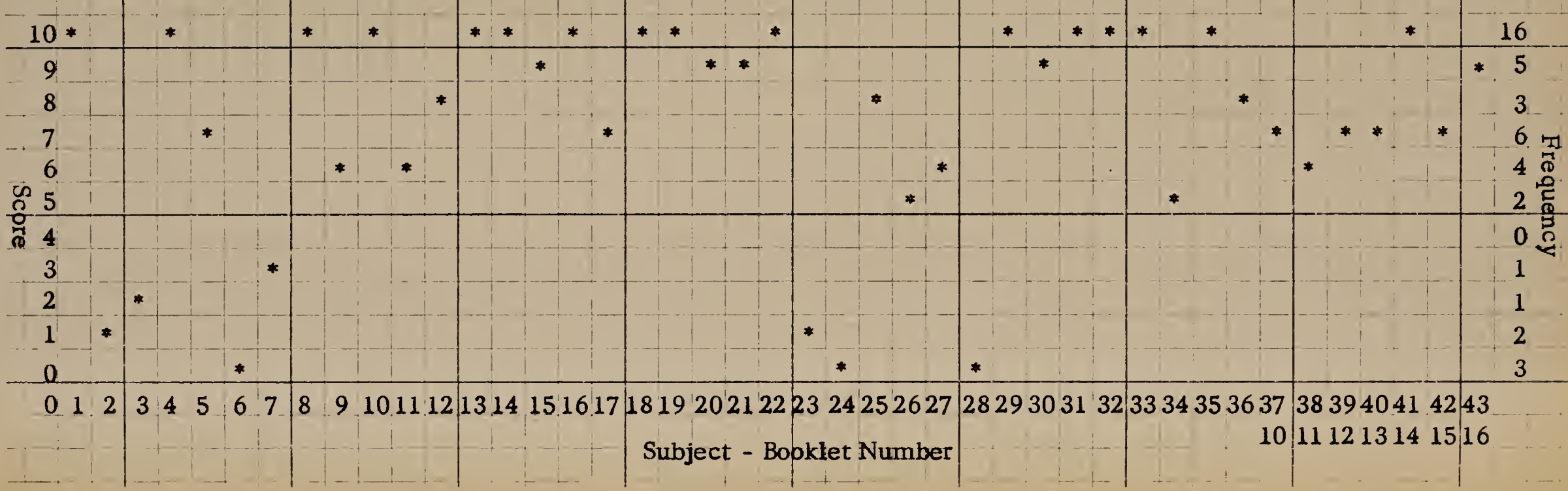


TABLE 15

RAW SCORE TALLY SHEET - MAP NUMBER 15/22X

Viewing Distance	2
Background	1
Line-Weight	3

$\overline{X} = 7.39$ $\sum fx = 318$

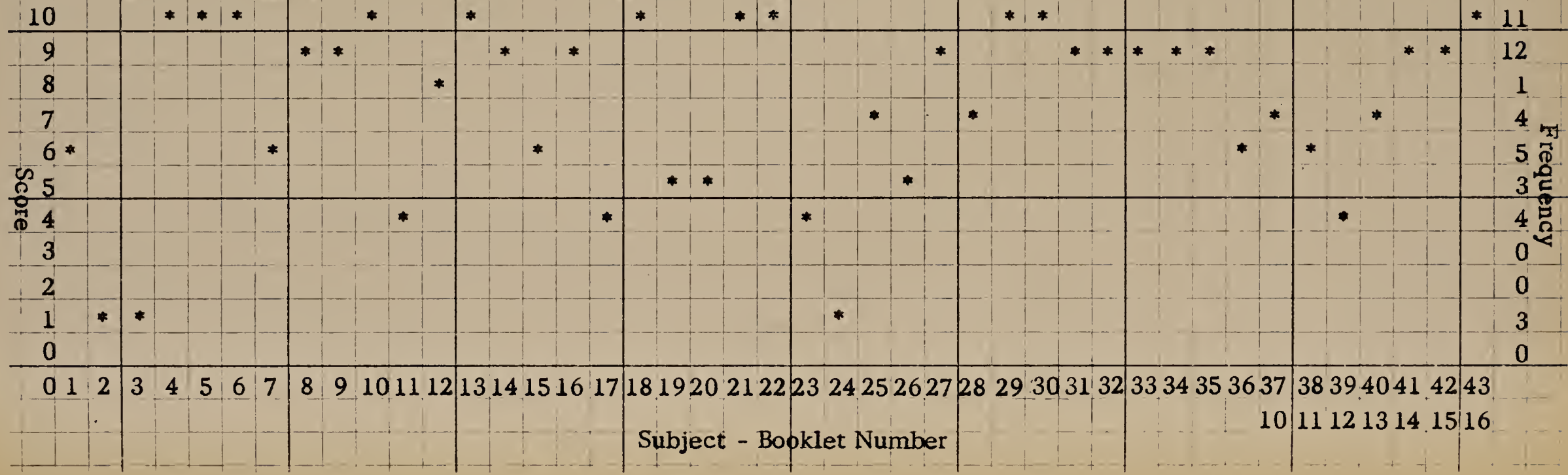


TABLE 16

RAW SCORE TALLY SHEET - MAP NUMBER 16/21X

Viewing Distance 2
Background 2
Line-Weight 1

$\bar{X} = 6.65$ $\sum fx = 286$

Score	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	Frequency
10		* *	*	* *	*		* * *	*	*	11	
9			*	*	*					*	3
8		*		*	*			*	*		5
7			*	*	*	*	*		*		7
6	*					*		*	* *		5
5						*		*			2
4			*								2
3	*	*									2
2					*		*				3
1											0
0			*			* *					3
	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	
								10	11 12 13 14 15	16	

Subject - Booklet Number

TABLE 17

RAW SCORE TALLY SHEET - MAP NUMBER 17/27X

Viewing Distance	2
Background	2
Line-Weight	2

$\bar{X} = 7.12$ $\quad \sum fx = 306$

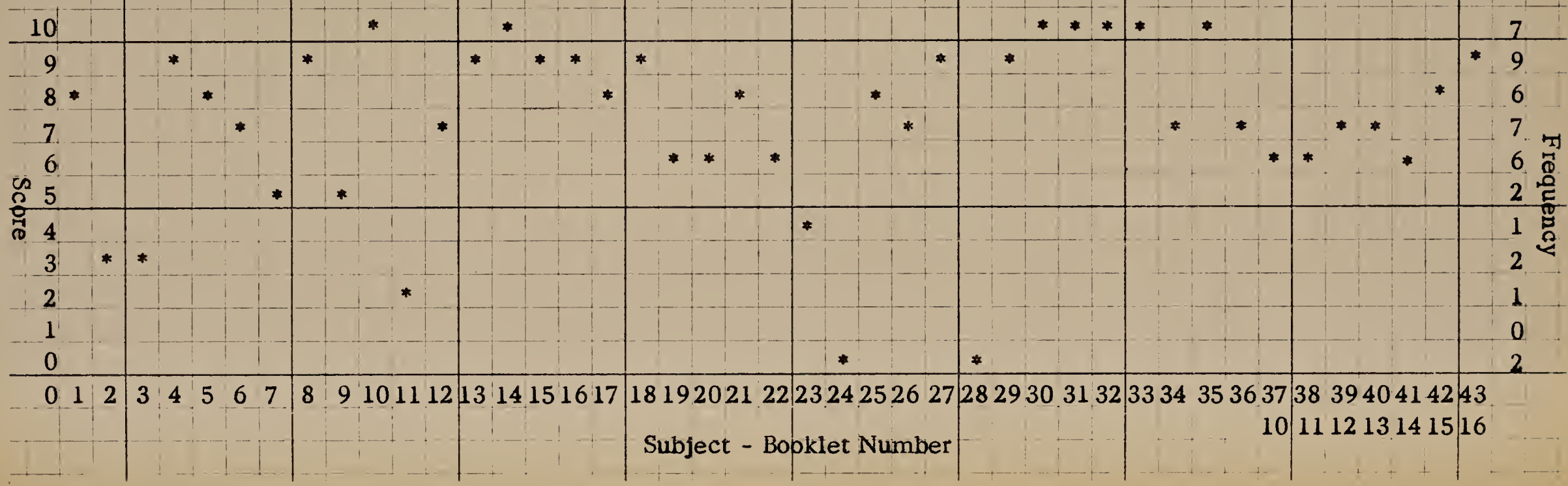


TABLE 18

RAW SCORE TALLY SHEET - MAP NUMBER 18/13X

Viewing Distance	2
Background	2
Line-Weight	3

$\bar{X} = 7.39$ $\sum fx = 318$

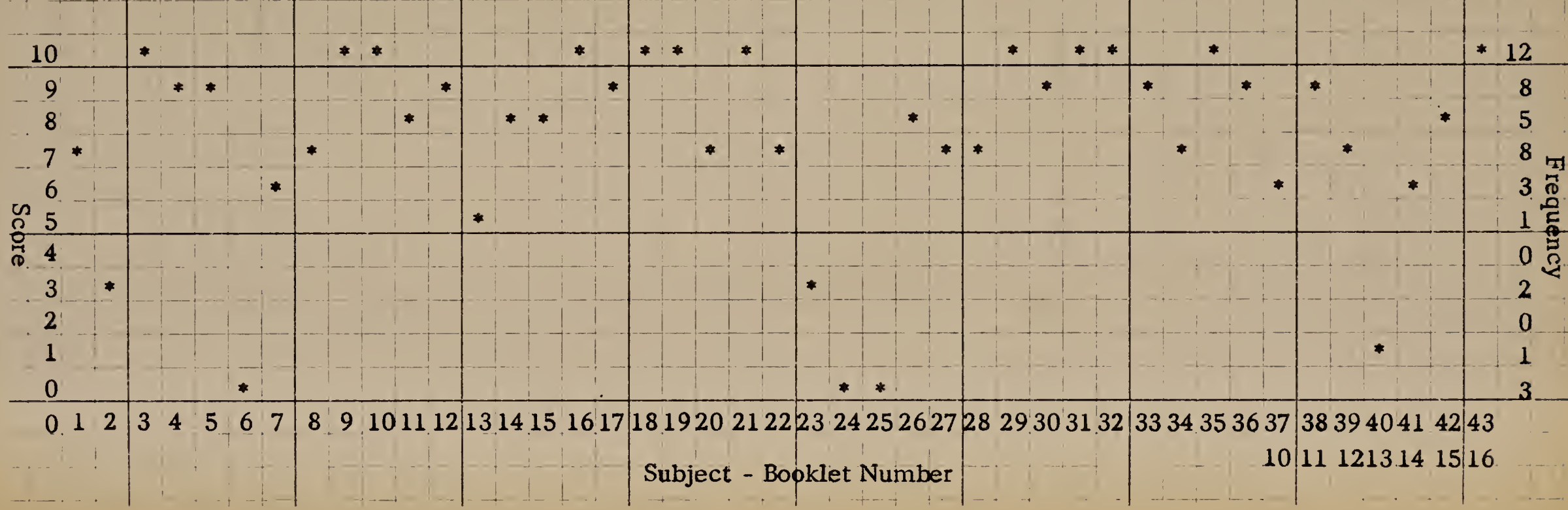


TABLE 19

RAW SCORE TALLY SHEET - MAP NUMBER 19/25X

Viewing Distance 2
Background 3
Line-Weight 1

$\overline{X} = 7.12$ $\sum fx = 306$

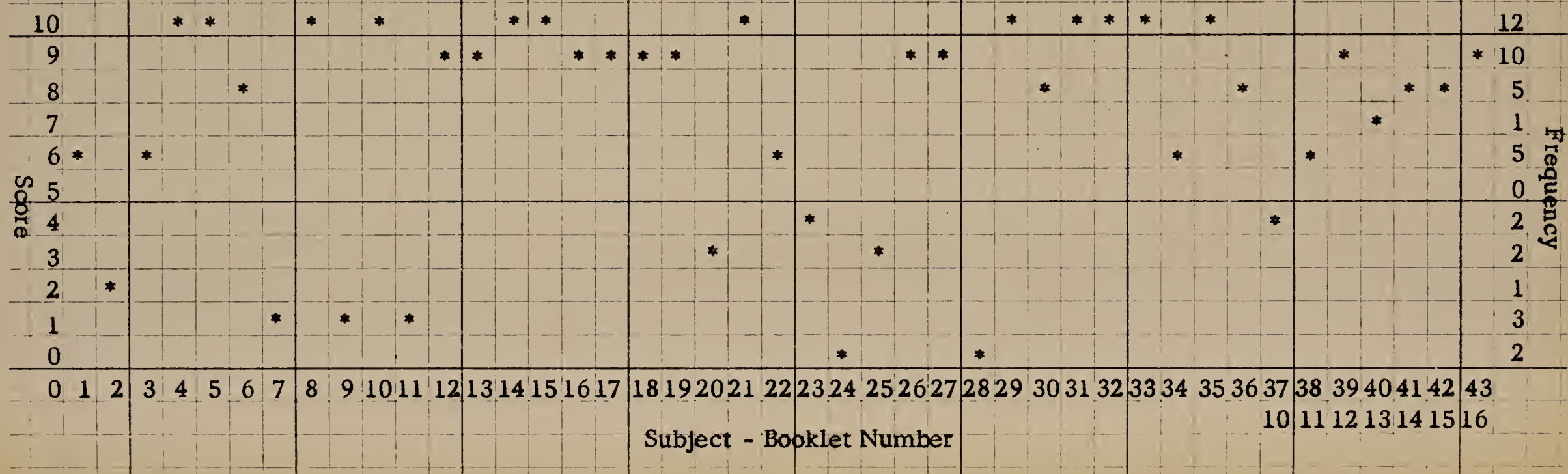


TABLE 20

RAW SCORE TALLY SHEET - MAP NUMBER 20/26X

Viewing Distance 2
Background 3
Line-Weight 2

$\bar{X} = 6.91$ $\sum fx = 297$

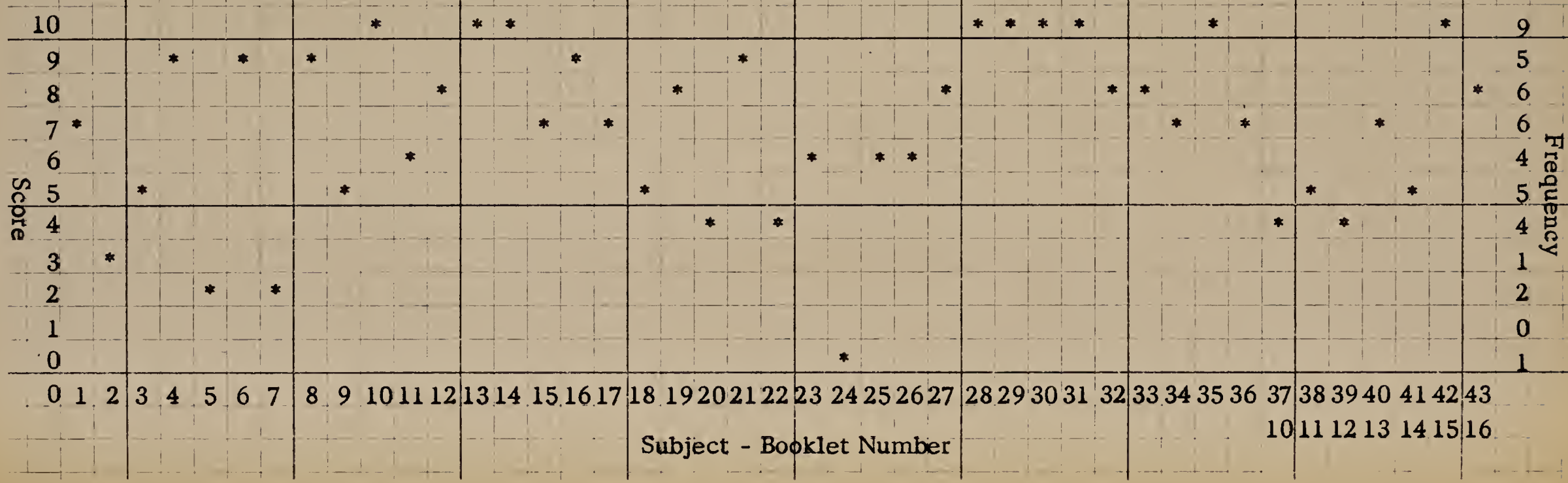


TABLE 21

RAW SCORE TALLY SHEET - MAP NUMBER 21/23X

Viewing Distance 2
Background 3
Line-Weight 3

$\bar{X}$ = 7.26 $\sum fx$ = 312

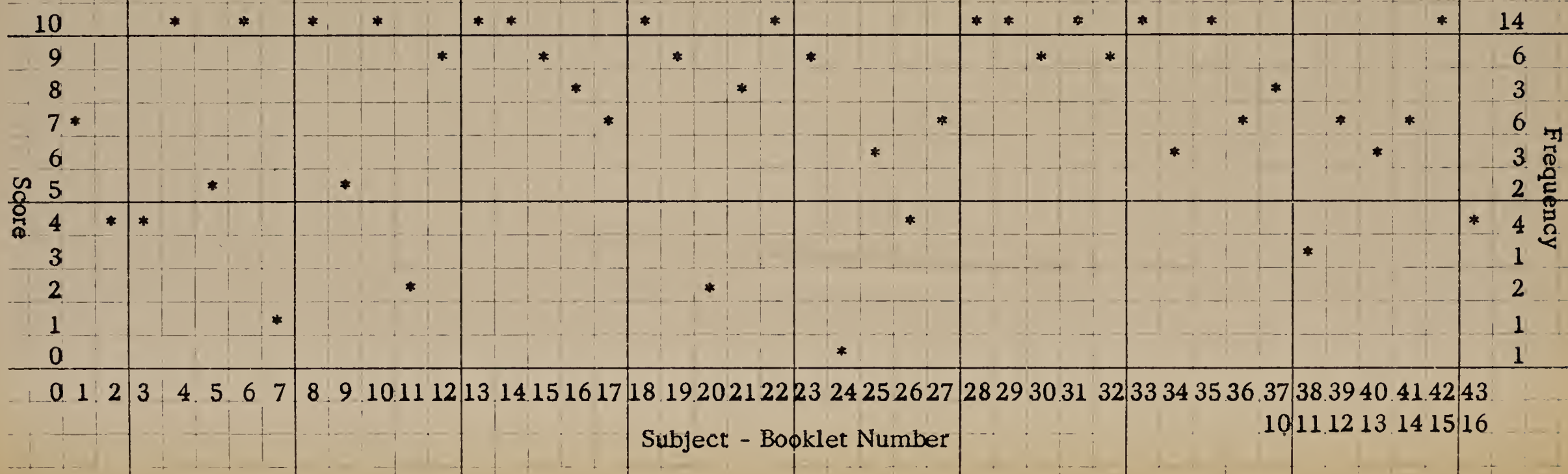


TABLE 22

RAW SCORE TALLY SHEET - MAP NUMBER 22/11X

Viewing Distance 2
Background 4
Line-Weight 1

$\bar{X} = 6.79$ $\sum fx = 292$

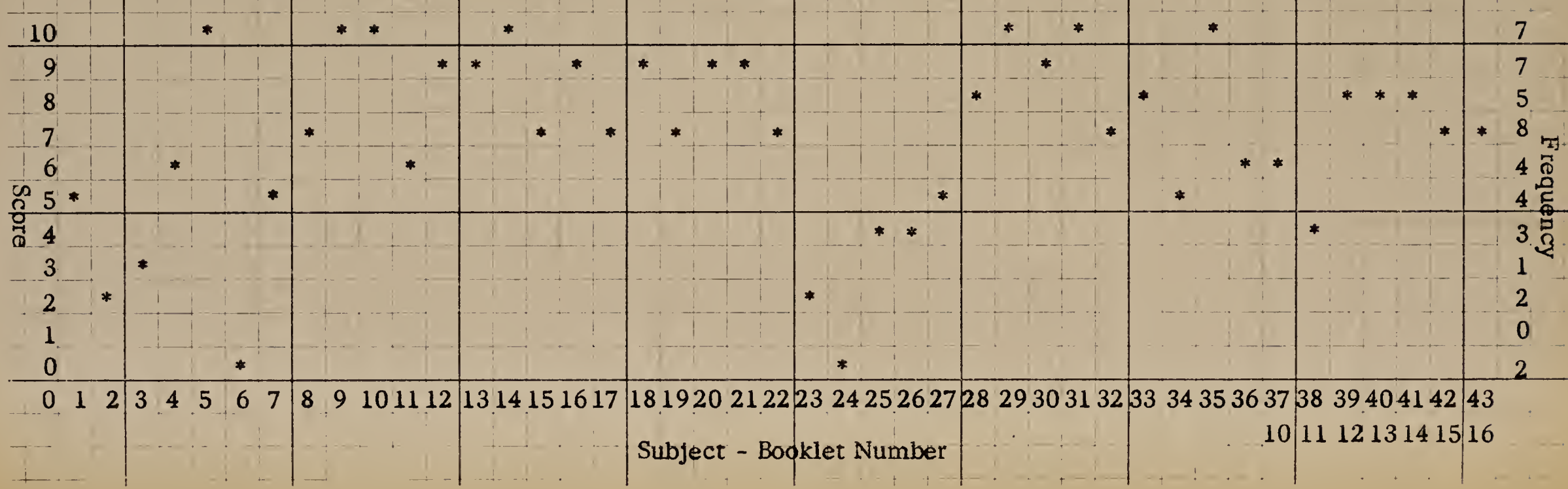


TABLE 23

RAW SCORE TALLY SHEET - MAP NUMBER 23/19X

Viewing Distance	2
Background	4
Line-Weight	2

$\bar{X} = 7.91$ $\quad \sum fx = 340$

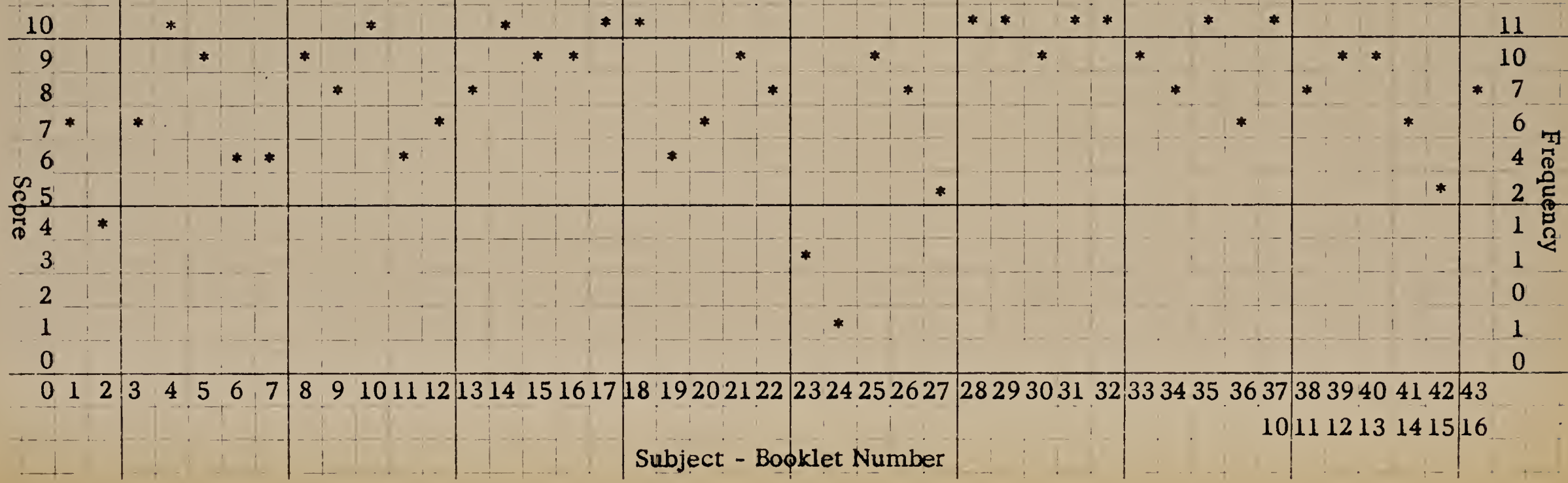


TABLE 24

RAW SCORE TALLY SHEET - MAP NUMBER 24/08X

Viewing Distance 2
Background 4
Line-Weight 3

$\overline{X}$ = 8.63 $\sum fx$ = 371

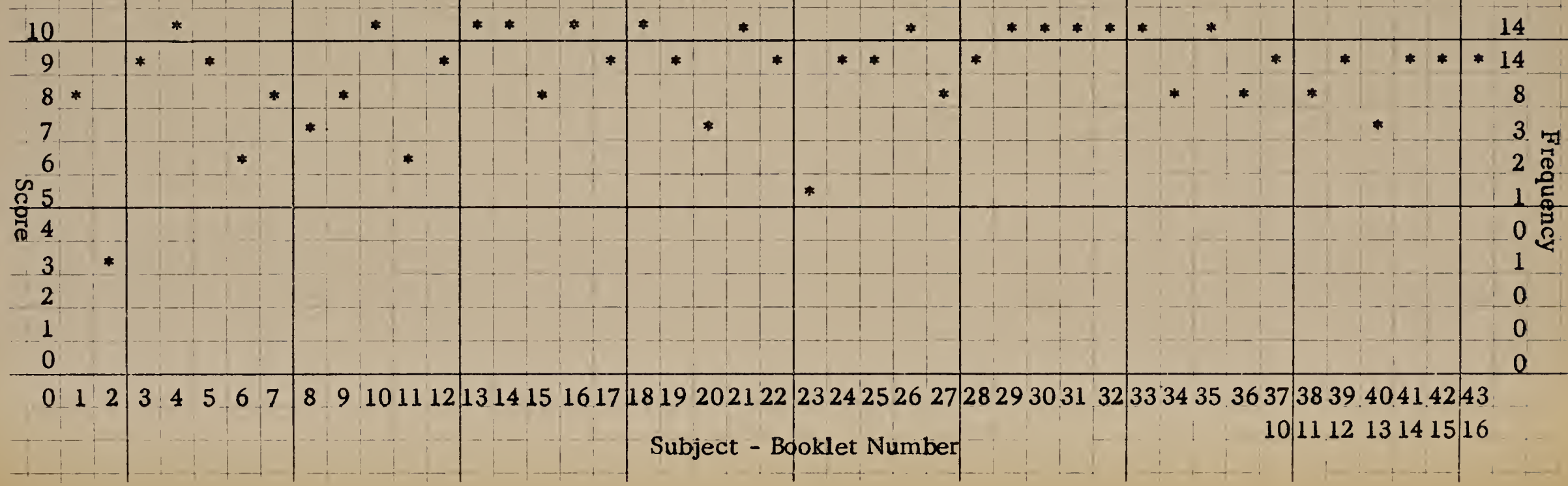


TABLE 25

RAW SCORE TALLY SHEET - MAP NUMBER 25/29X

Viewing Distance 3
Background 1
Line-Weight 1

$\overline{X}$ = 5.81 $\sum fx$ = 250

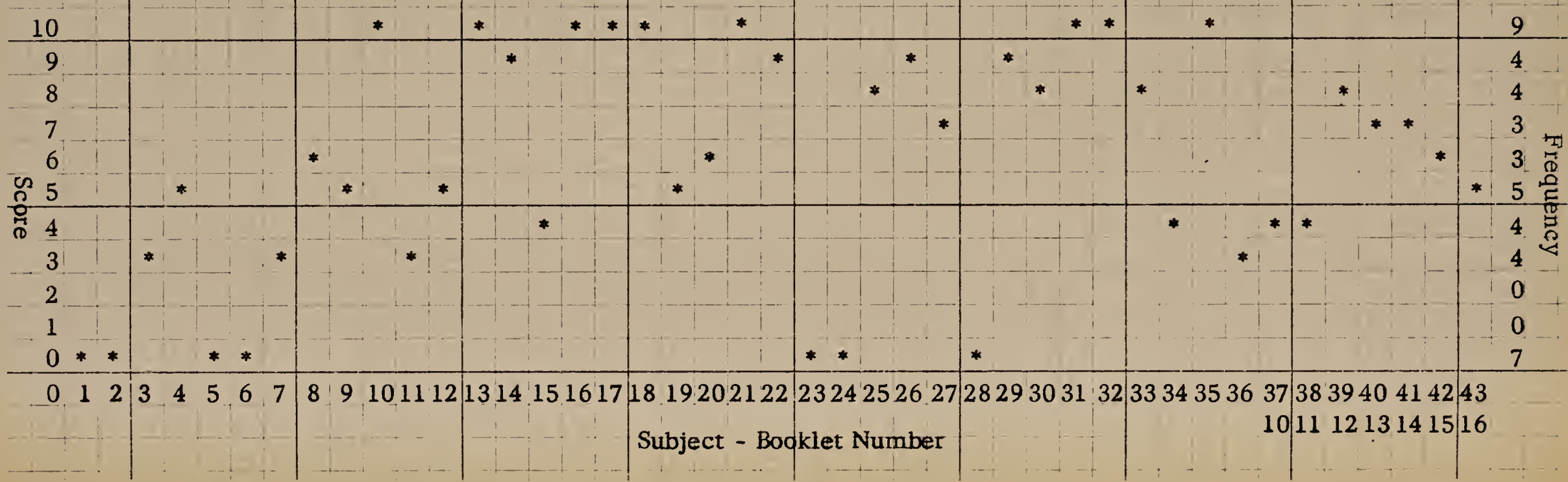


TABLE 26

RAW SCORE TALLY SHEET - MAP NUMBER 26/18X

Viewing Distance 3
Background 1
Line-Weight 2

$\bar{X} = 6.67$ $\sum fx = 287$

Score	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	Frequency
10			* *	* * * *	*		* * * * *			11	
9		*	* *				*	*		5	
8				*	* * *				*	5	
7				*		*			* *	4	
6	*	*			*	*			*	*	6
5								*	*		2
4		*						*			2
3						*					1
2		*	*			*					3
1	*										1
0	*					*	*				3
	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	
					Subject - Booklet Number			10	11 12 13 14 15	16	

TABLE 27

RAW SCORE TALLY SHEET - MAP NUMBER 27/14X

Viewing Distance 3
Background 1
Line-Weight 3

$\overline{X} = 7.23$ $\sum fx = 311$

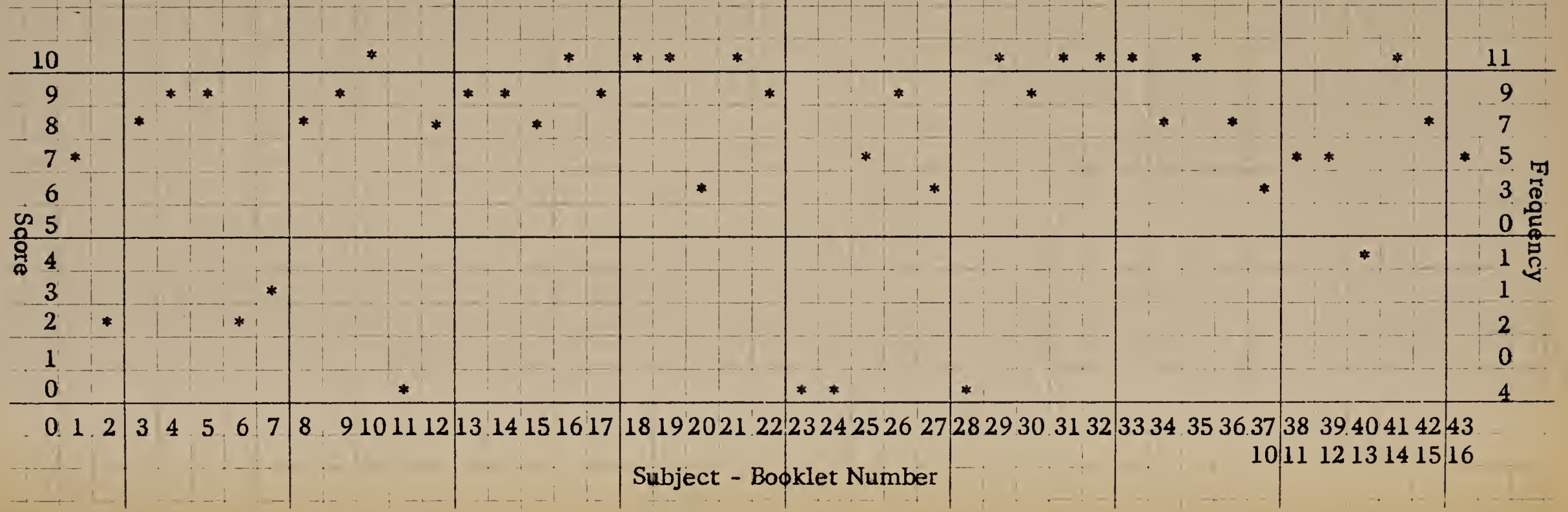


TABLE 28

RAW SCORE TALLY SHEET - MAP NUMBER 28/06X

Viewing Distance	3
Background	2
Line-Weight	1

$\bar{X} = 6.21$ $\sum fx = 267$

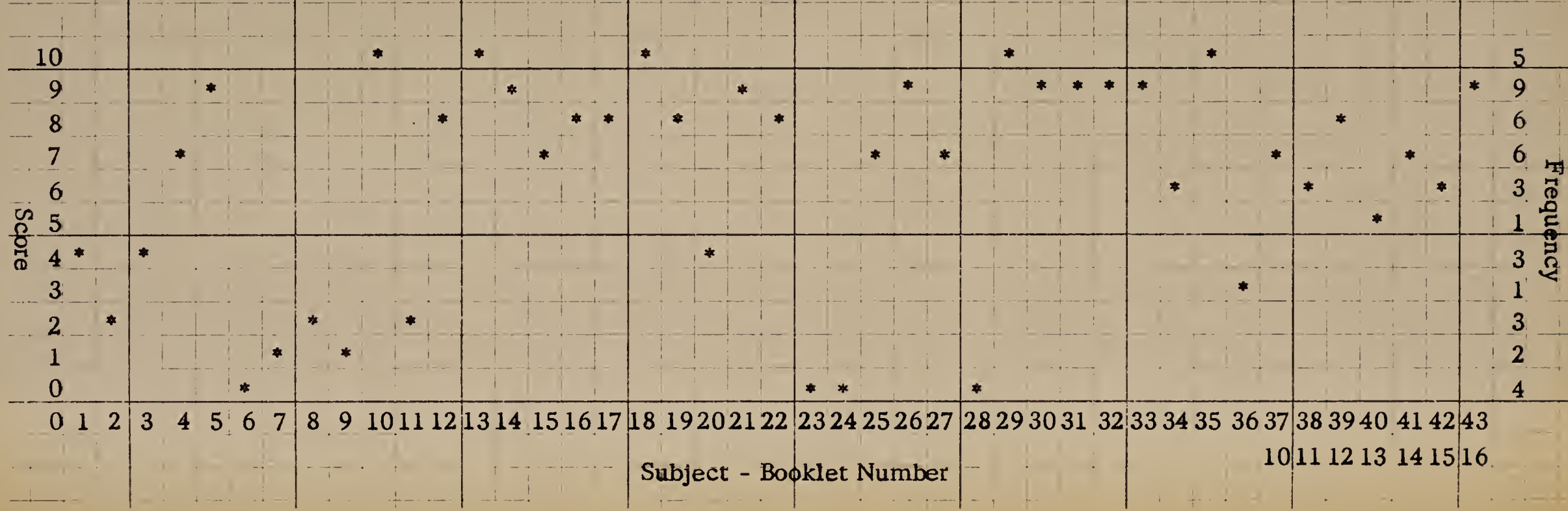


TABLE 29

RAW SCORE TALLY SHEET - MAP NUMBER 29/28X

Viewing Distance 3
Background 2
Line-Weight 2

$\bar{X}$ = 6.58 $\sum fx$ = 281

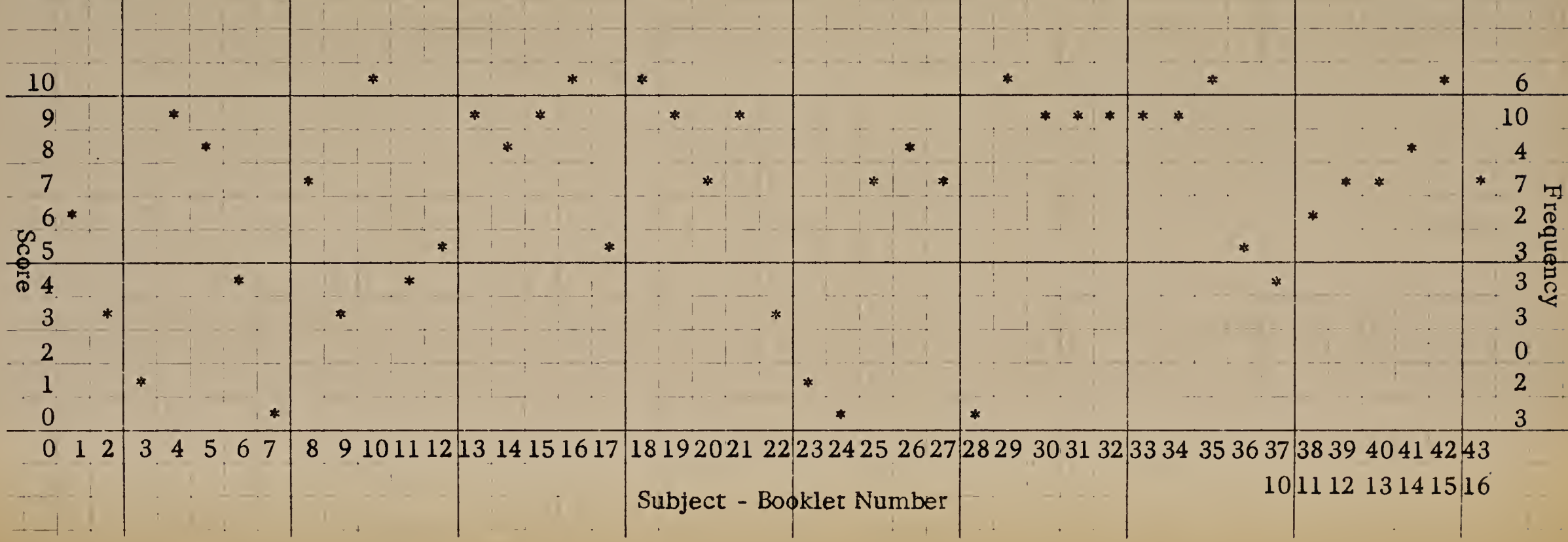


TABLE 30

RAW SCORE TALLY SHEET - MAP NUMBER 30/07X

Viewing Distance 3
Background 2
Line-Weight 3

$\overline{X} = 6.74$ $\sum fx = 290$

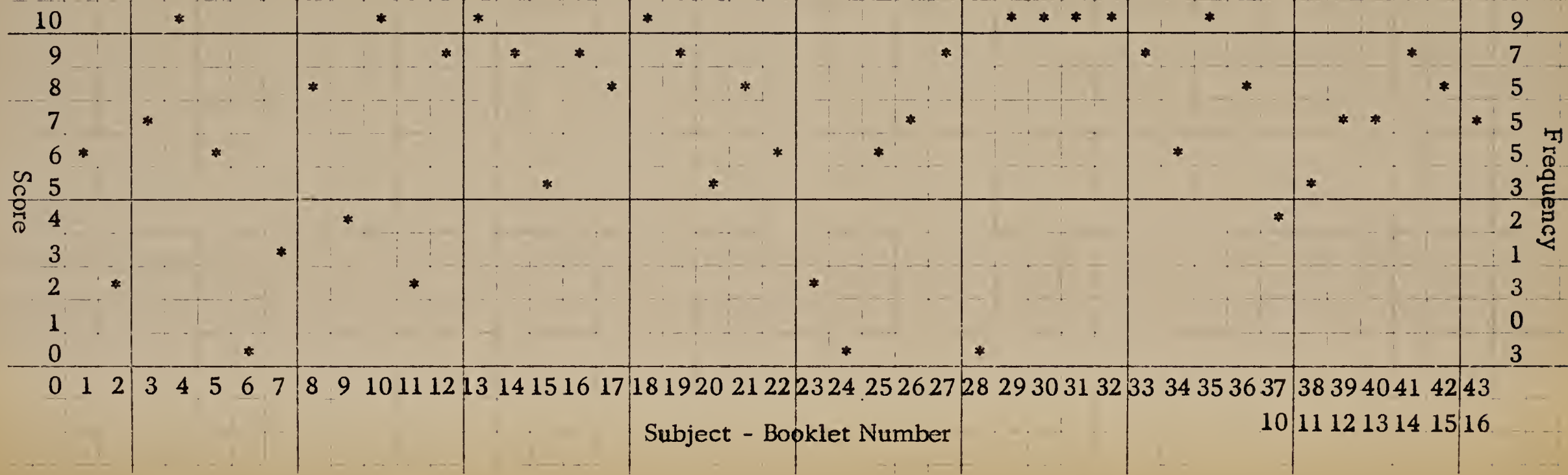


TABLE 31

RAW SCORE TALLY SHEET - MAP NUMBER 31/17X

Viewing Distance 3
Background 3
Line-Weight 1

$\bar{X} = 6.18$ $\sum fx = 266$

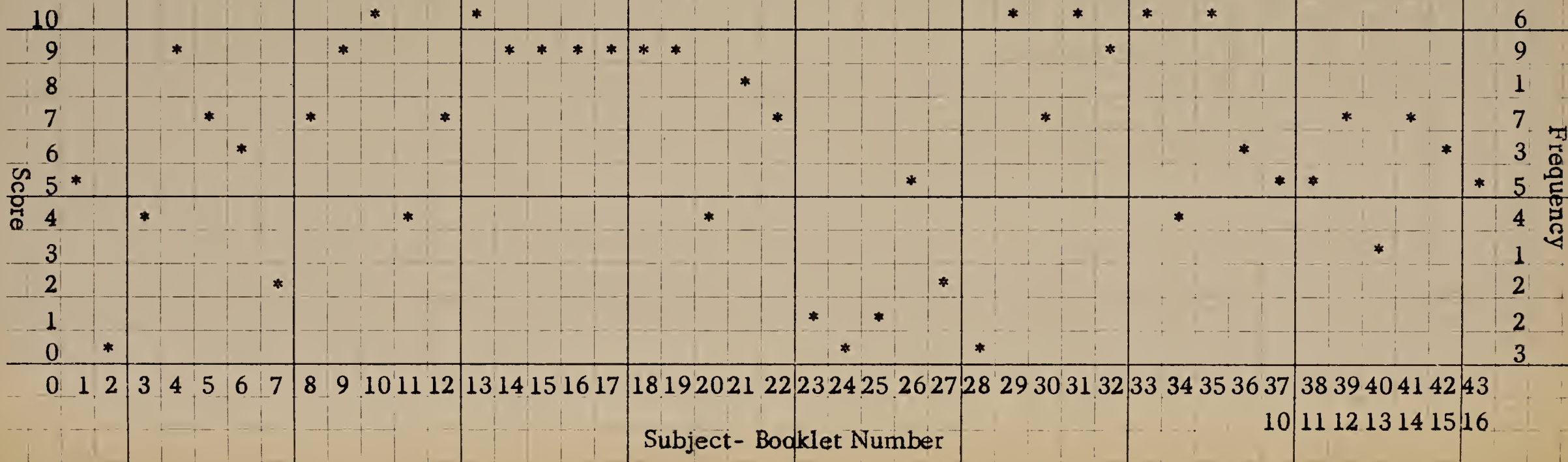


TABLE 32

RAW SCORE TALLY SHEET - MAP NUMBER 32/10X

Viewing Distance 3
Background 3
Line-Weight 2

$\overline{X}$ = 6.77 $\sum fx$ = 291

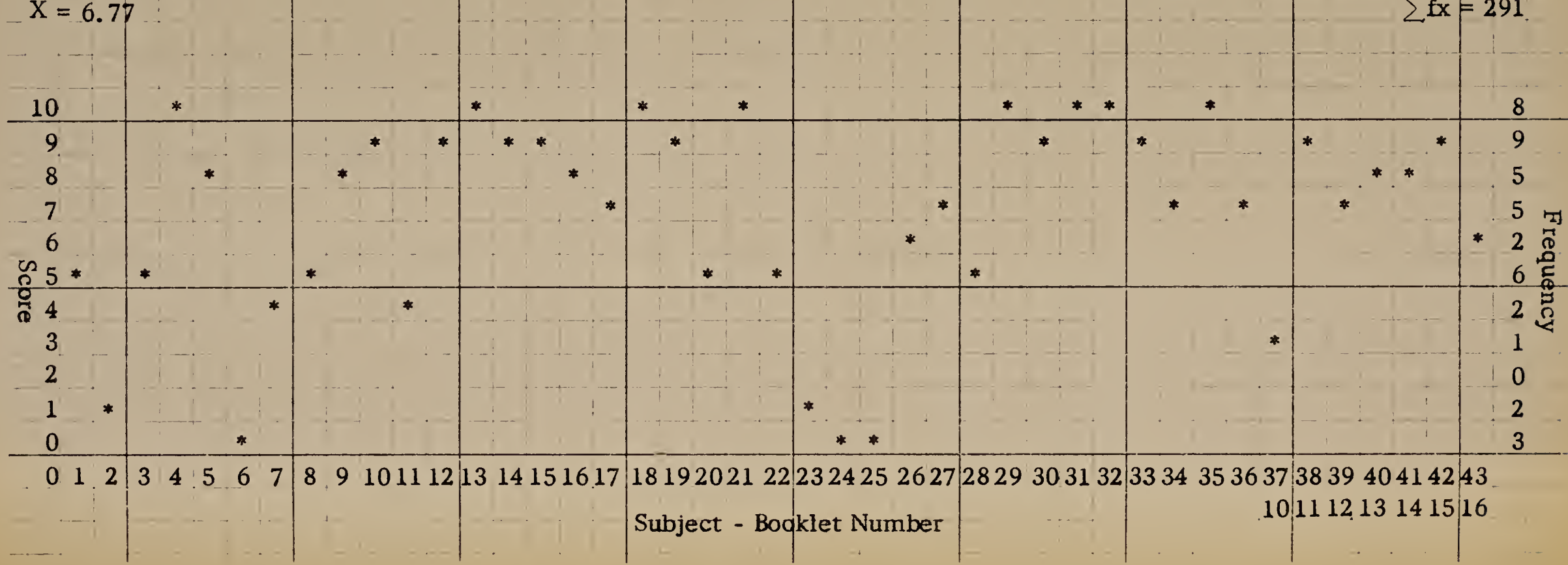


TABLE 33

RAW SCORE TALLY SHEET - MAP NUMBER 33/12X

Viewing Distance 3
Background 3
Line-Weight 3

$\bar{X} = 6.69$ $\sum fx = 288$

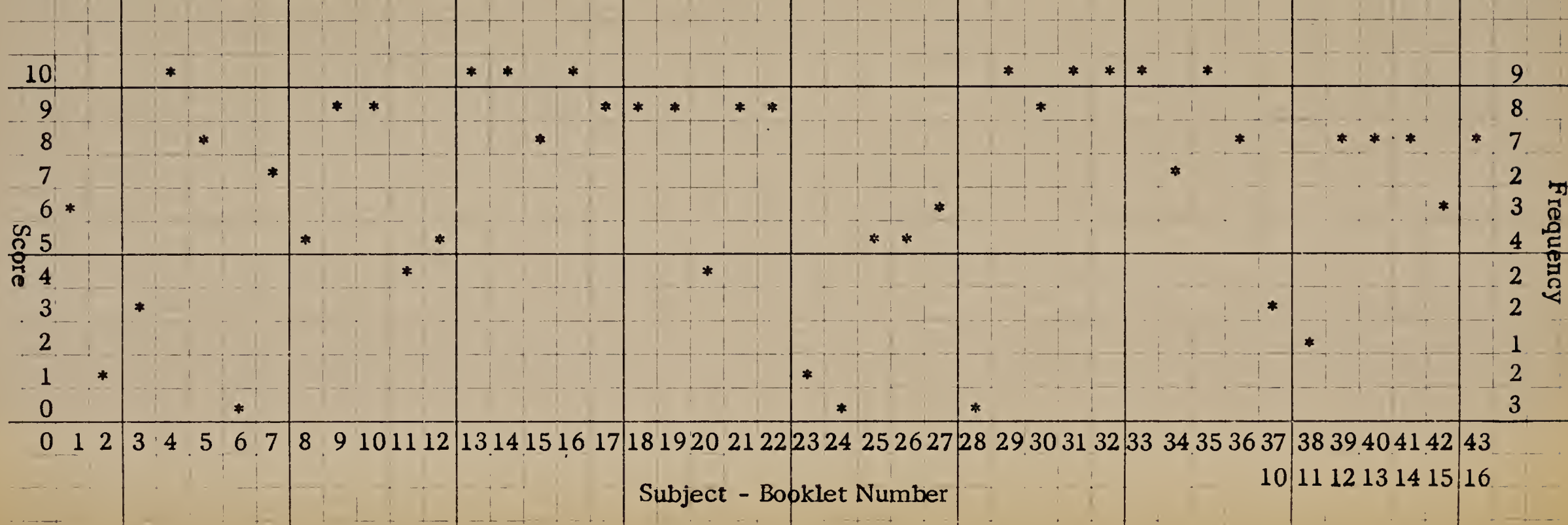


TABLE 34

RAW SCORE TALLY SHEET - MAP NUMBER 34/34X

Viewing Distance 3
Background 4
Line-Weight 1

$\overline{X}$ = 6.33 $\sum fx$ = 272

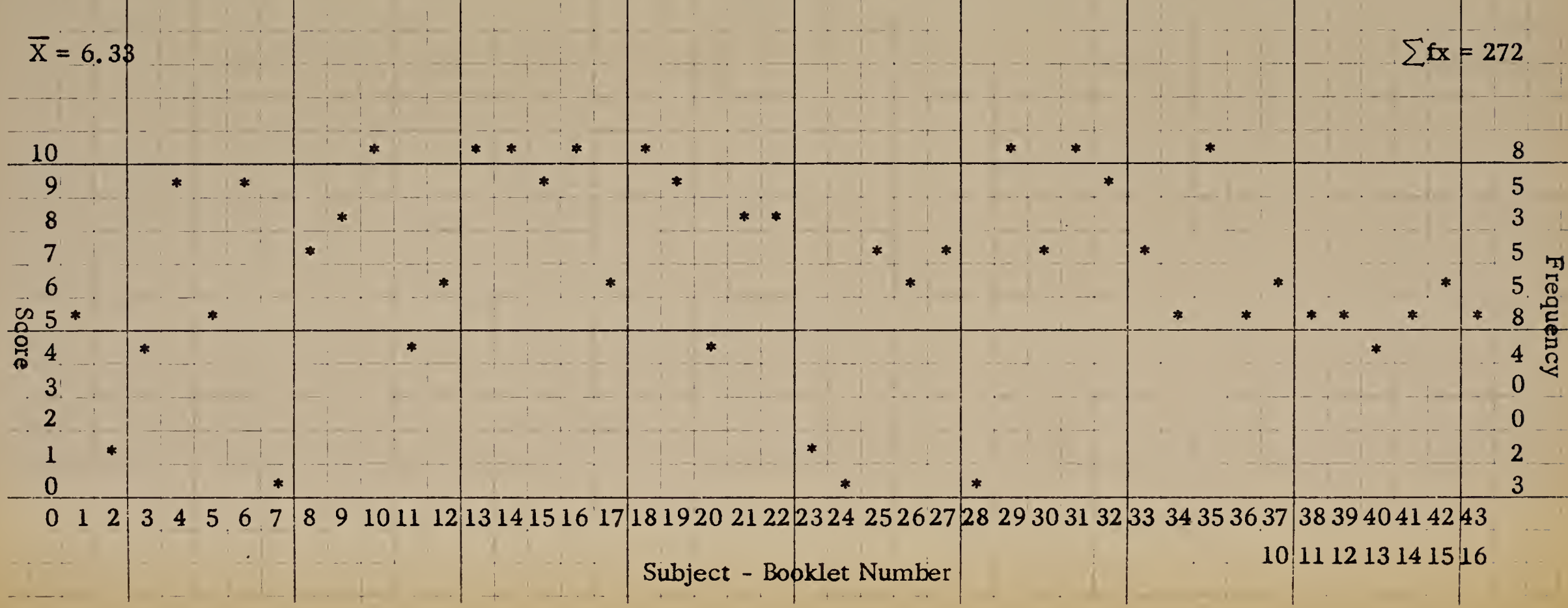


TABLE 35

RAW SCORE TALLY SHEET - MAP NUMBER 35/05X

Viewing Distance	3
Background	4
Line-Weight	2

$\overline{X} = 6.81$ $\sum fx = 293$

Score	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	Frequency
10			*	* * * *	*		* * *	*			9
9		*	*		* * *	*	*	* *			9
8		*	*	* *					*		5
7		*									1
6			*			*			*	*	4
5								* *	* *		4
4	*				*	* *					4
3	*	* *	*							*	5
2											0
1											0
0						*	*				2
	0 1 2	3 4 5 6 7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42	43	
					Subject - Booklet Number			10	11 12 13 14 15	16	

TABLE 36

RAW SCORE TALLY SHEET - MAP NUMBER 36/20X

Viewing Distance 3
Background 4
Line-Weight 3

$\overline{X}$ = 6.74

$\sum fx$ = 290

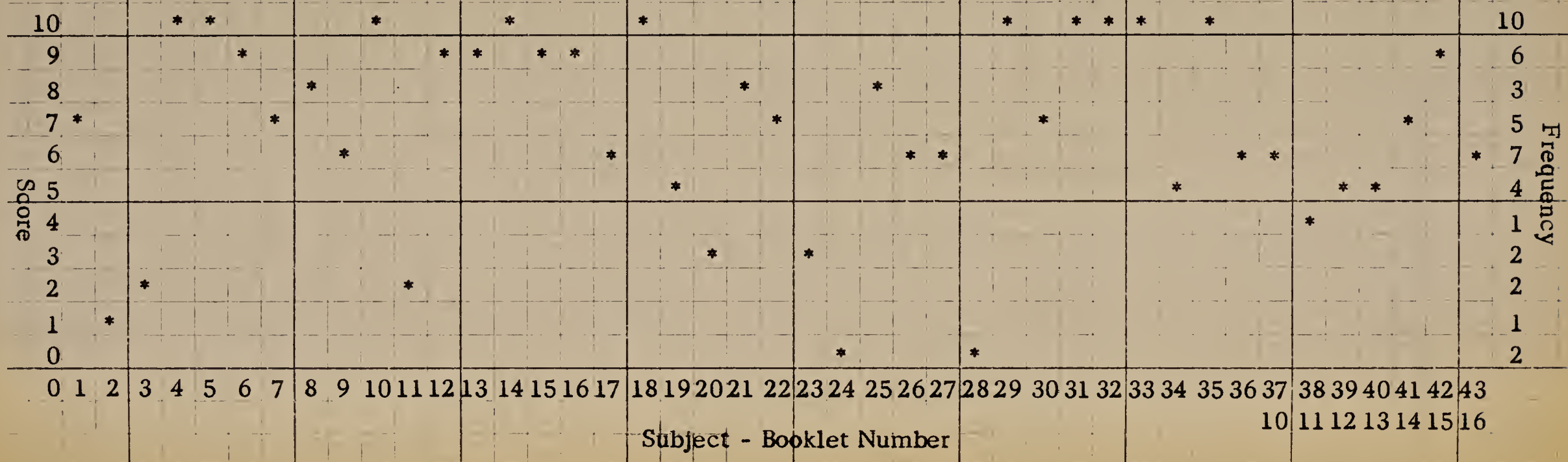


TABLE 37

MAP RANK AND SCORE SUMMARY

Map Readability Ranking	Test Scores 43 Ss. Responses/Map		Map Numbers Systematic Order	Map Characteristics*			Map Numbers Random Order (X)
	Σ Points	Mean ($\bar{X}$)		Viewing Distance Cases (VD)	Background Cases (BK)	Line-Width Cases (LW)	
1	371	8.63	24	2	4	3	08
2	367	8.53	11	1	4	2	30
3	362	8.42	02	1	1	2	31
4	361	8.39	10	1	4	1	32
5	358	8.33	12	1	4	3	01
6	356	8.28	09	1	3	3	16
7	355	8.26	08	1	3	2	02
8	354	8.23	04	1	2	1	09
9	352	8.19	03	1	1	3	36
10	341	7.93	05	1	2	2	35
11	340	7.91	23	2	4	2	19
12	333	7.74	06	1	2	3	04
13.5, 13.5	318	7.39	15, 18	2, 2	1, 2	3, 3	22, 13
15.5, 15.5	312	7.26	14, 21	2, 2	1, 3	2, 3	03, 23
17.5, 17.5	311	7.23	13, 27	2, 3	1, 1	1, 3	33, 14
19	310	7.21	07	1	3	1	24
20.5, 20.5	306	7.12	17, 19	2, 2	2, 3	2, 1	27, 25
22	300	6.98	01	1	1	1	15
23	297	6.91	20	2	3	2	26
24	293	6.81	35	3	4	2	05
25	292	6.79	22	2	4	1	11
26	291	6.77	32	3	3	2	10
27.5, 27.5	290	6.74	30, 36	3, 3	2, 4	3, 3	07, 20
29	288	6.69	33	3	3	3	12
30	287	6.67	26	3	1	2	18
31	286	6.65	16	2	2	1	21
32	281	6.53	29	3	2	2	28
33	272	6.33	34	3	4	1	34
34	267	6.21	28	3	2	1	06
35	266	6.18	31	3	3	1	17
36	250	5.81	25	3	1	1	29
	Range: 121 points (250-371)	Range: 2.82 units 0-10 scale		* 1 - 7" 2 - 14" 3 - 21"	*1 -White 2 -Light Gray 3 -Dark Gray 4 -Black	*1- 0.015" 2- 0.030" 3- 0.045"	

LEGEND - Abbreviations, Tables 37-47:

A, B, C, D, E, F - Code letters for sequences of test factor cases.

VD - Viewing Distance; BK - Background; LW - Line-Width

V - Specific factor cases arranged in varied manner on graphic distribution (1 2 3 1 2 3) or (1 2 3 4 1 2 3 4).

SK - Specific factor cases arranged in semi-constant manner on graphic distribution (1 1 1 2 2 2 3 3 3 1 1 1 2 2 2 3 3 3) or (1 1 1 2 2 2 3 3 3 4 4 4) or (1 1 1 1 2 2 2 2 3 3 3 3).

K - Specific factor cases arranged in constant manner on graphic distribution (1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 3 3) or (1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 4 4 4 4 4 4 4 4 4 4).

Ss. - Subjects; $\bar{X}$ - Mean or Smoothed-Mean Values; X - Random Order Map Numbers

										Order Codes;	
14	06	28	07	17	10	12	34	05	20		X
3	1	2	3	1	2	3	1	2	3		V
1	2	2	2	3	3	3	4	4	4		SK
3	3	3	3	3	3	3	3	3	3		X

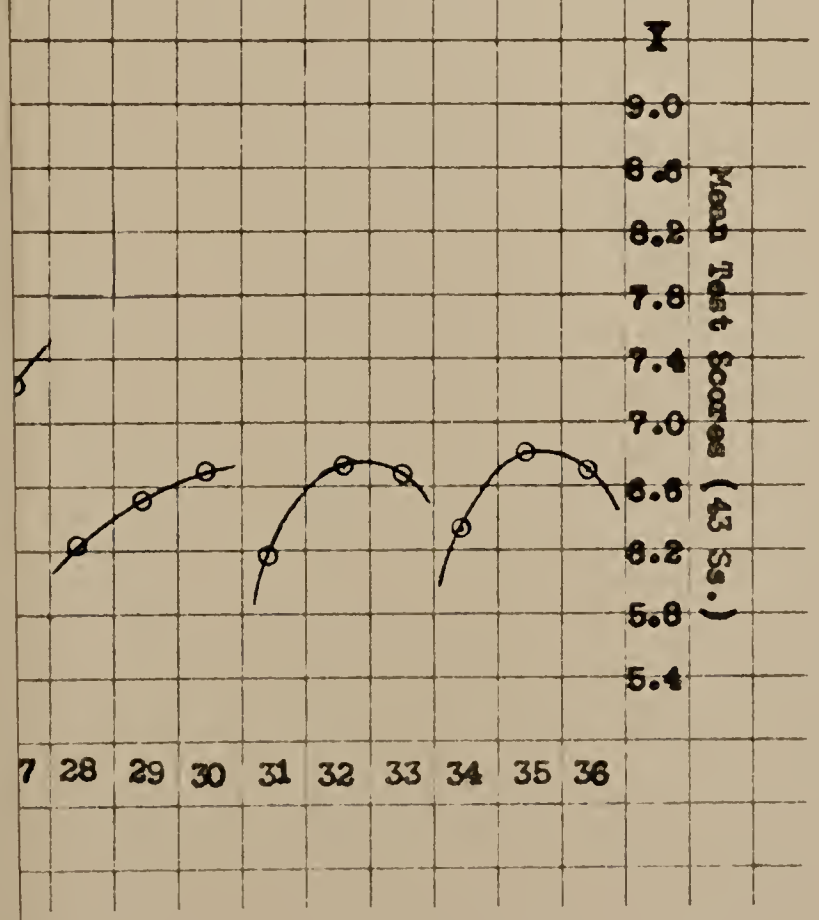
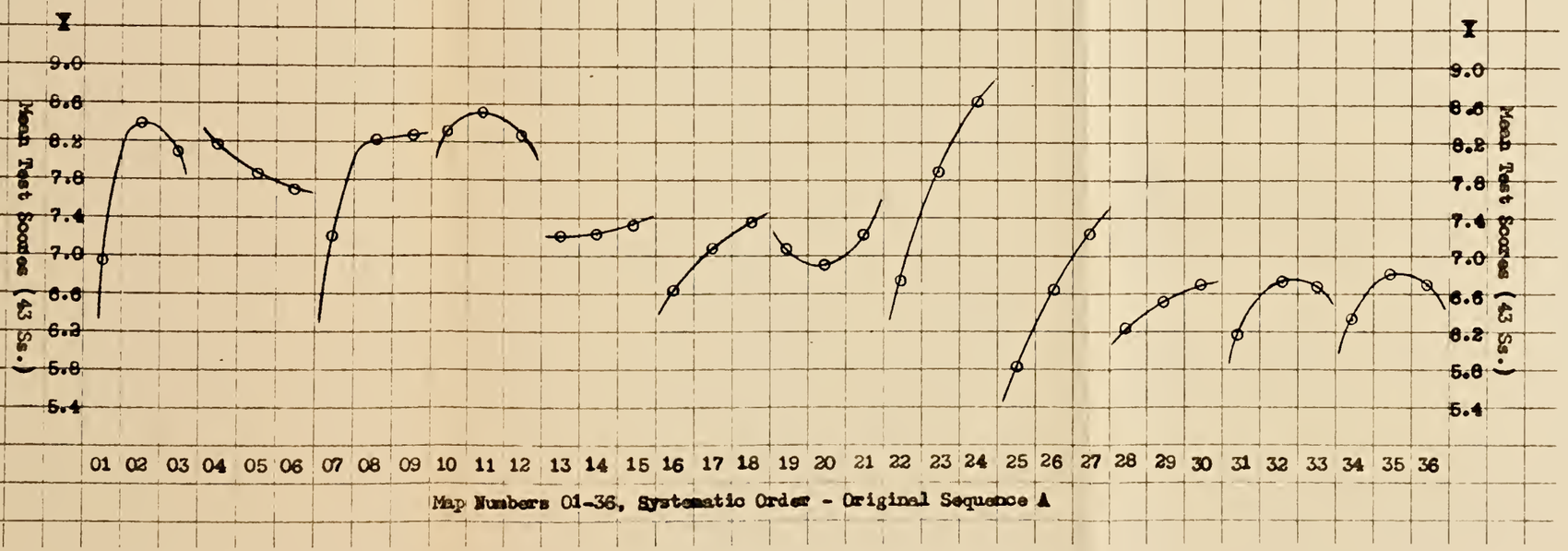


TABLE 38

MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR LINE-WIDTH EFFECTS ON BACKGROUNDS AND VIEWING DISTANCES

																																			Order Codes:
Random Test-Order Numbers	15	31	36	09	35	04	24	02	16	32	30	01	33	03	22	21	27	13	25	28	23	11	19	08	29	18	14	06	28	07	17	10	12	34	05	20		X
Line-Width Cases	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		V
Background Cases	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4		SK
Viewing Distance Cases	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3		K



										Order Codes:	
7	34	18	28	10	05	14	07	12	20		X
3	4	1	2	3	4	1	2	3	4		V
	1	2	2	2	2	3	3	3	3		SK
	3	3	3	3	3	3	3	3	3		K

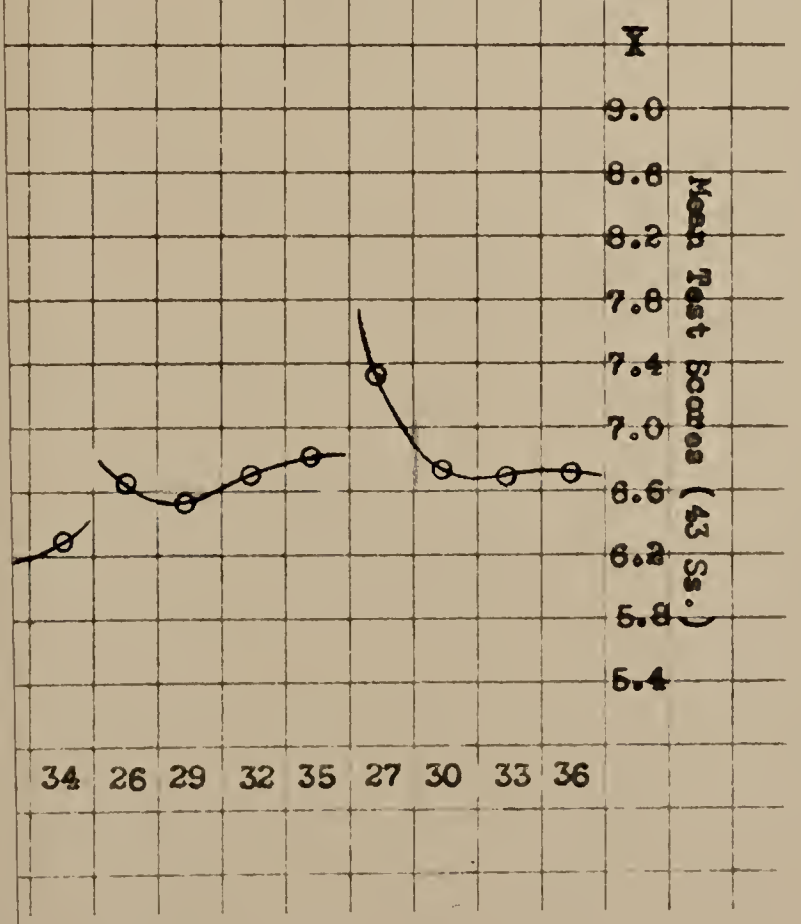
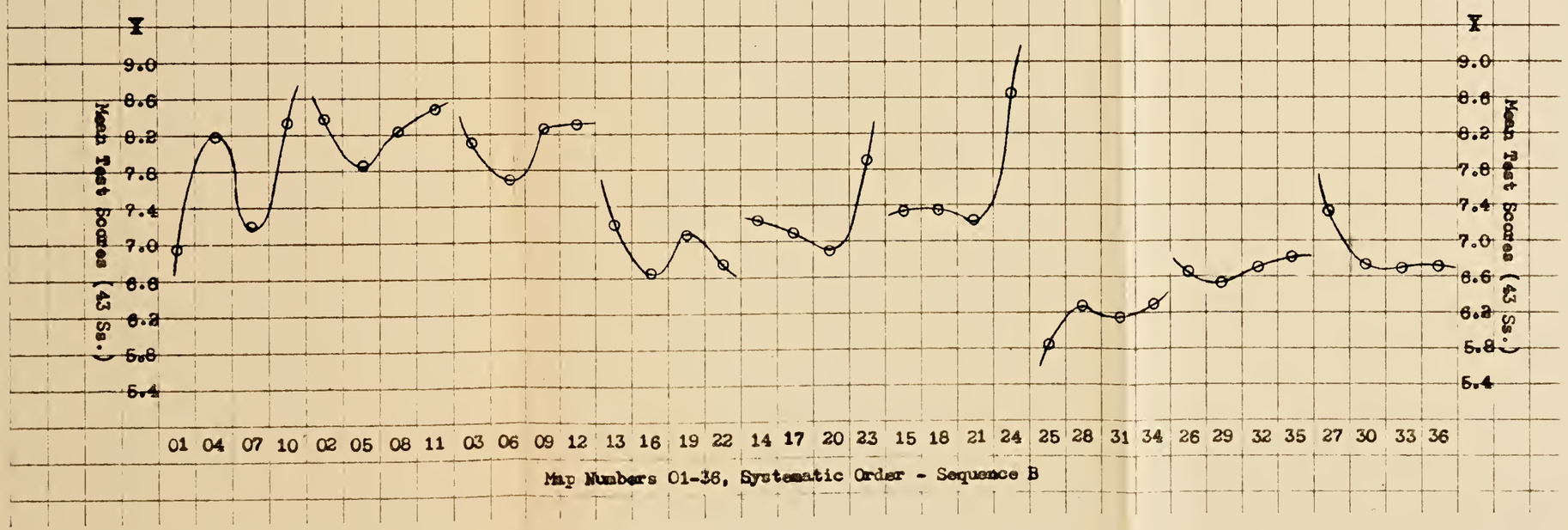


TABLE 39

MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR BACKGROUND EFFECTS ON LINE-WIDTHS AND VIEWING DISTANCES

																																			Order Codes:
Random Test-Order Numbers	15	09	24	32	31	35	02	30	36	04	16	01	33	21	25	11	03	27	26	19	22	13	23	08	29	06	17	34	18	28	10	05	14	07	12	20	X
Background Cases	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	V
Line-Width Cases	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3	SK
Viewing Distance Cases	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	K



										Order Codes:		
2	32	11	34	30	19	05	01	08	20		X	
3	1	2	3	1	2	3	1	2	3		V	
3	1	1	1	2	2	2	3	3	3		SK	
3	4	4	4	4	4	4	4	4	4		K	

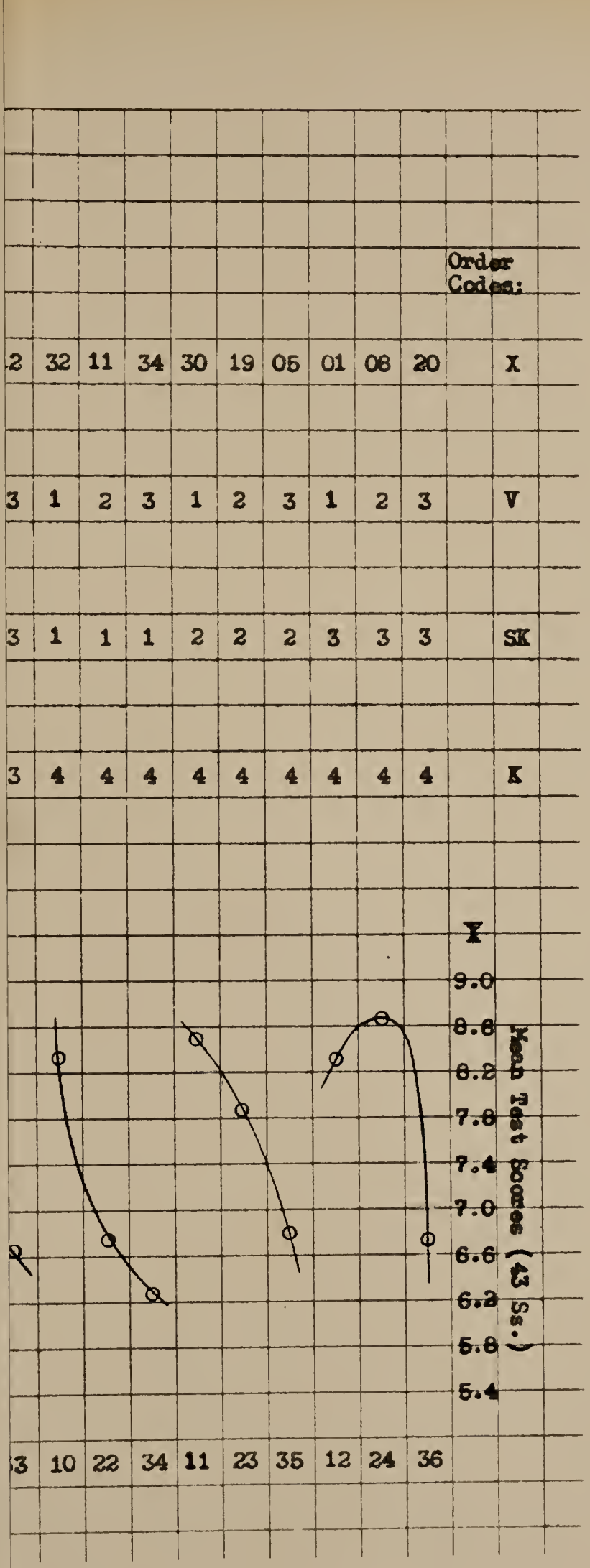
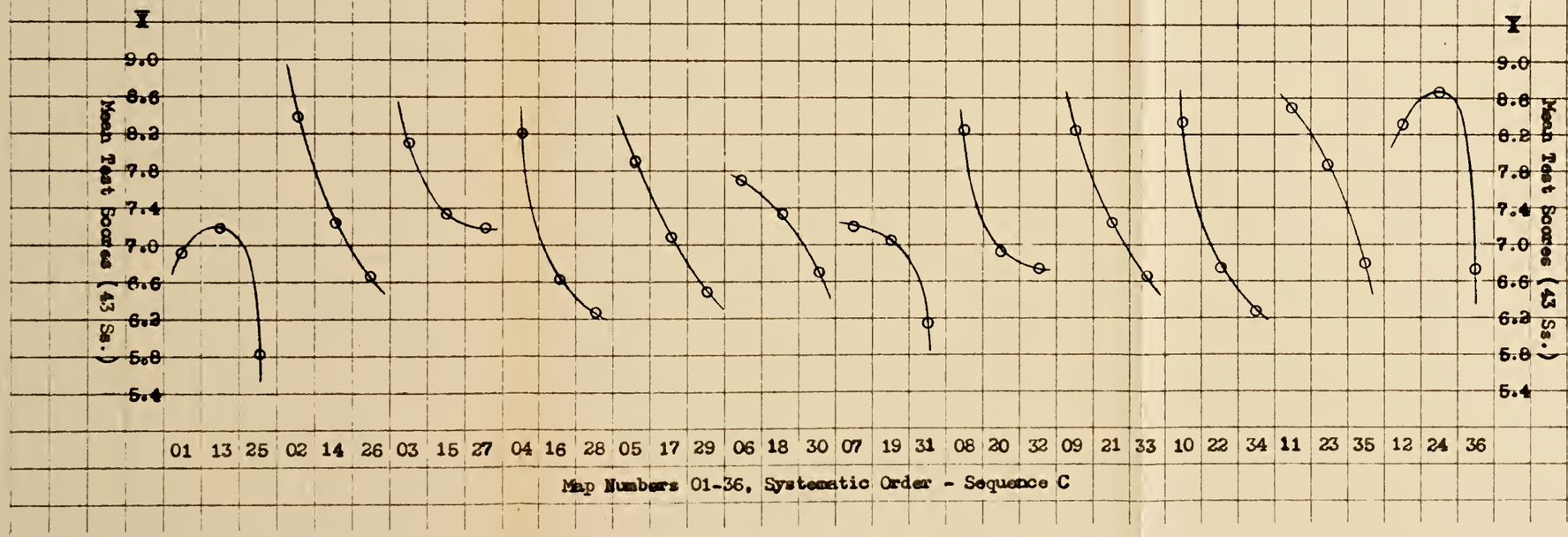


TABLE 40

MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR VIEWING DISTANCE EFFECTS ON LINE-WIDTHS AND BACKGROUNDS

																																			Order Codes:
Random Test-Order Numbers:	15	33	29	31	03	18	36	22	14	09	21	06	35	27	28	04	13	07	24	25	17	02	26	10	16	23	12	32	11	34	30	19	05	01	08	20	X
Viewing Distance Cases	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	V
Line-Width Cases	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	SK
Background Cases	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	K



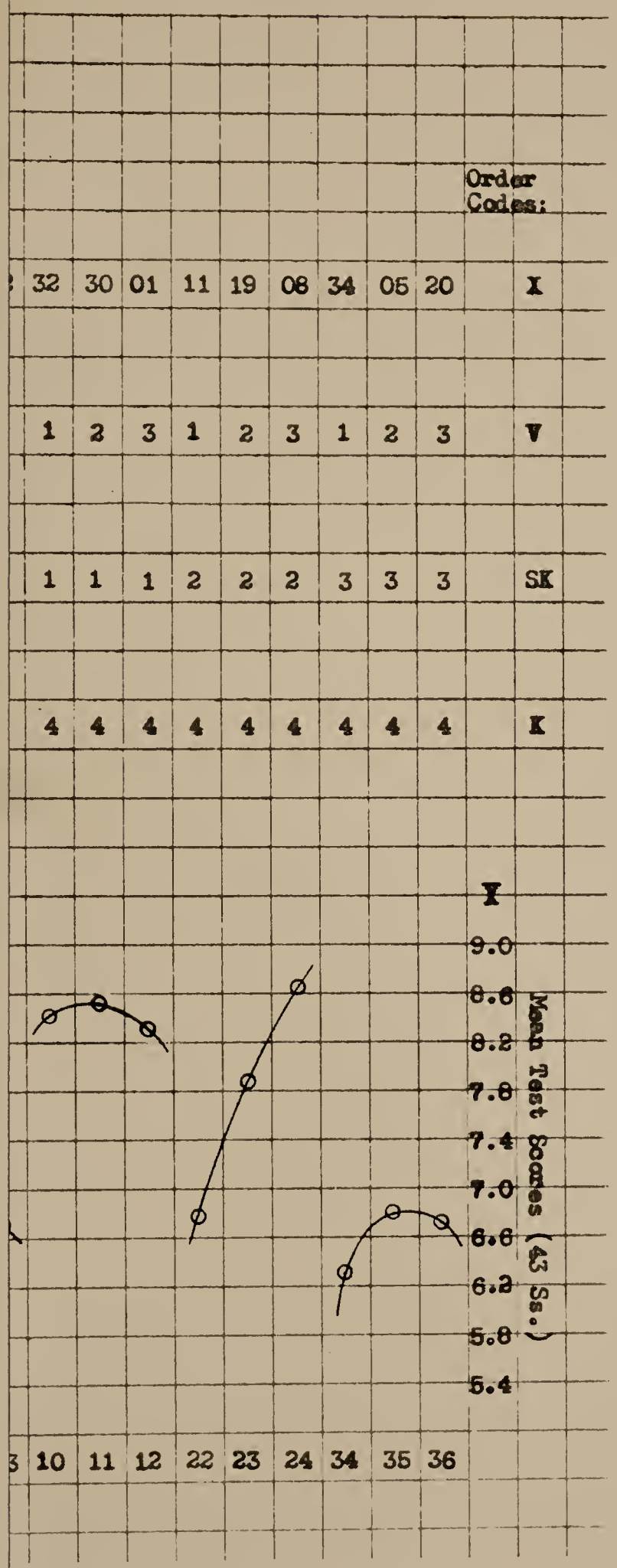
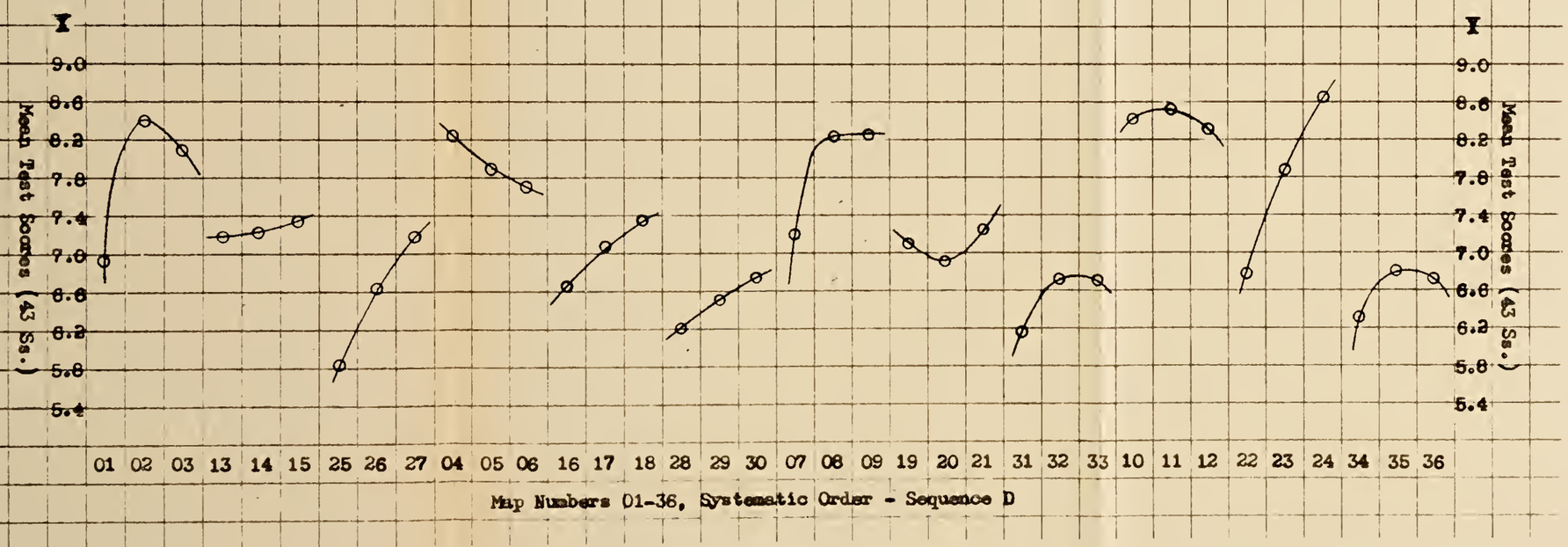

Order Codes:
32 30 01 11 19 08 34 05 20 X
1 2 3 1 2 3 1 2 3 V
1 1 1 2 2 2 3 3 3 SK
4 4 4 4 4 4 4 4 4 K
I
9.0
8.6
8.2
7.8
7.4
7.0
6.6
6.2
5.8
5.4
Mean Test Scores (43 Ss.)
3 10 11 12 22 23 24 34 35 36

TABLE 41

MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR LINE-WIDTH EFFECTS ON VIEWING DISTANCES AND BACKGROUNDS

																																			Order Codes:
Random Test-Order Numbers	15	31	36	33	03	22	29	18	14	09	35	04	21	27	13	06	28	07	24	02	16	25	26	23	17	10	12	32	30	01	11	19	08	34	05	20		X
Line-Width Cases	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		V
Viewing Distance Cases	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3		SK
Background Cases	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4		K



										Order Codes:	
16	01	22	13	23	08	14	07	12	20		X
3	4	1	2	3	4	1	2	3	4		V
1	1	2	2	2	2	3	3	3	3		SX
3	3	3	3	3	3	3	3	3	3		X

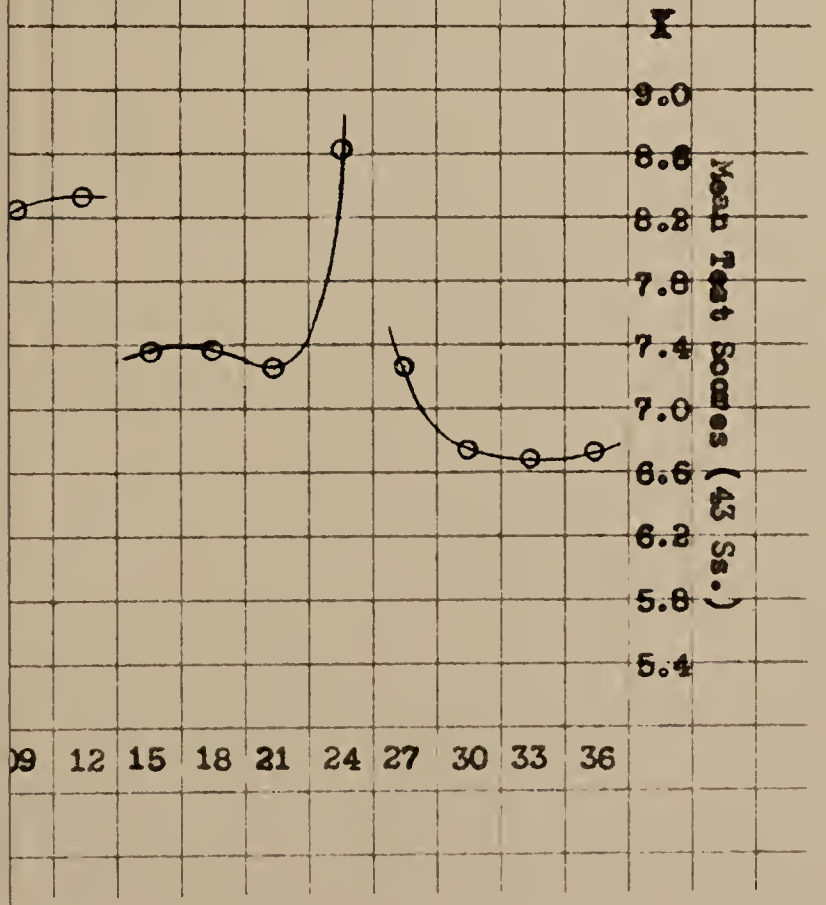
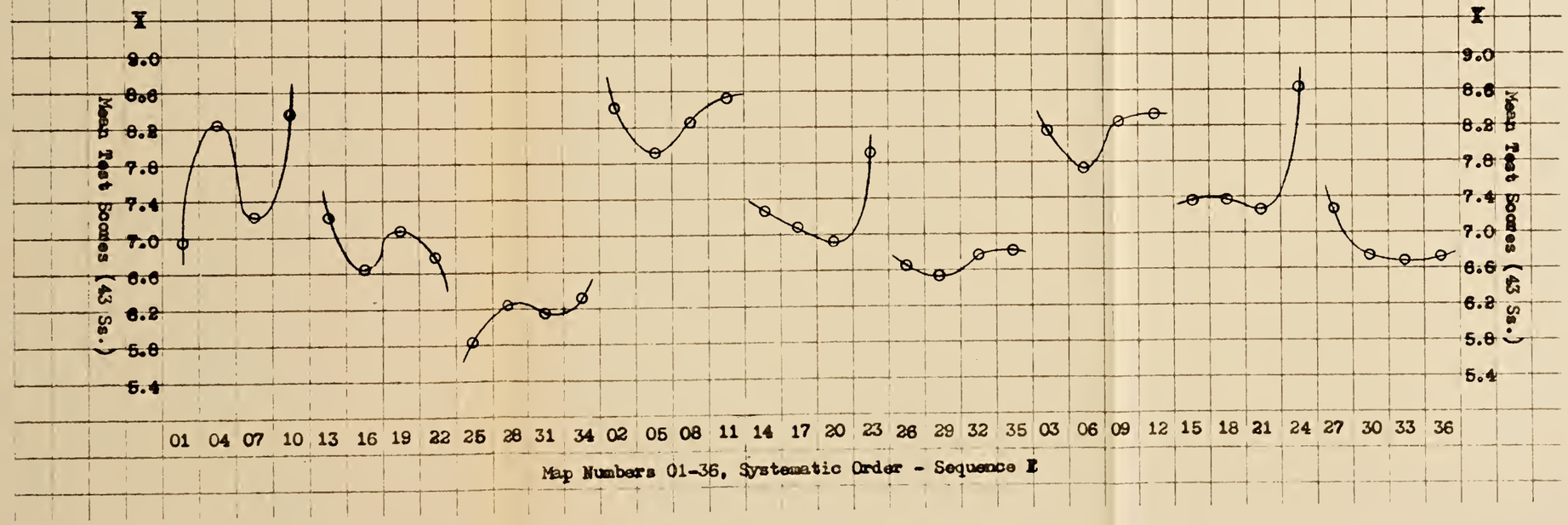


TABLE 42

MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR BACKGROUND EFFECTS ON VIEWING DISTANCES AND LINE-WIDTHS

																																		Order Codes:
Random Test-Order Numbers	15	09	24	32	33	21	25	11	29	06	17	34	31	35	02	30	03	27	26	19	18	28	10	05	36	04	16	01	22	13	23	08	14	07	12	20		X
Background Cases	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4		V
Viewing Distance Cases	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3		SK
Line-Width Cases	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3		K



										Order Codes:	
4	04	13	07	16	23	12	01	08	20		X
3	1	2	3	1	2	3	1	2	3		V
1	2	2	2	3	3	3	4	4	4		SK
3	3	3	3	3	3	3	3	3	3		K

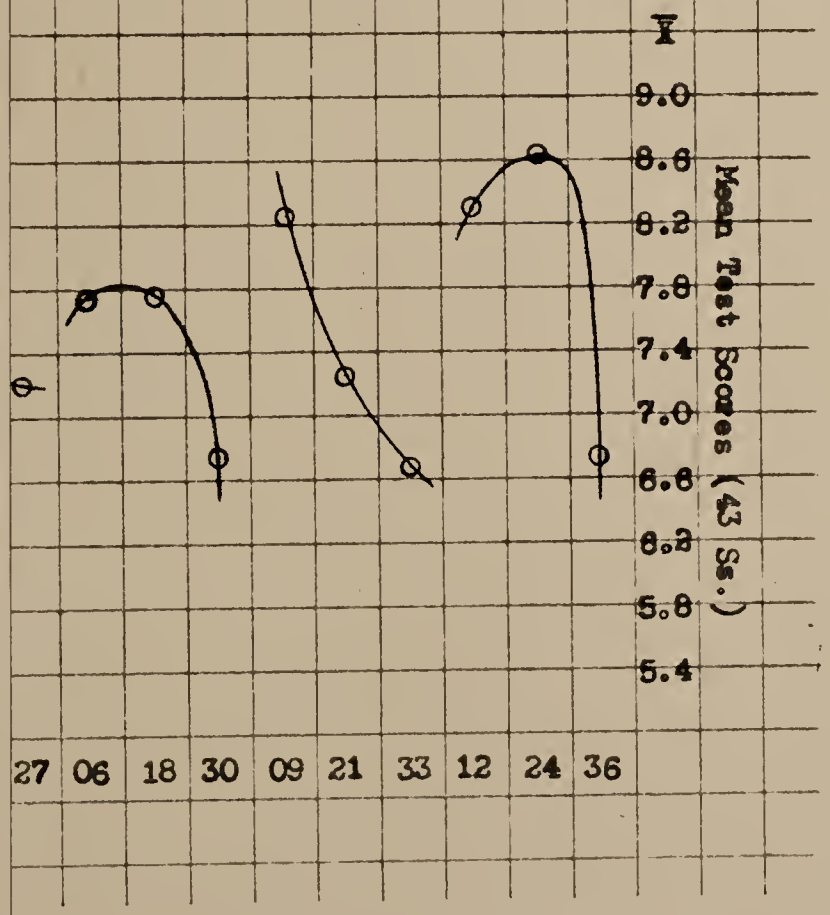


TABLE 43

MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR VIEWING DISTANCE EFFECTS ON BACKGROUNDS AND LINE-WIDTHS

																																		Order Codes:	
Random Test-Order Numbers	15	33	29	09	21	06	24	25	17	32	11	34	31	03	18	35	27	28	02	26	10	30	19	05	36	22	14	04	13	07	16	23	12	01	08	20		X
Viewing Distance Cases	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		V
Background Cases	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4		SK
Line-Width Cases	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3		K

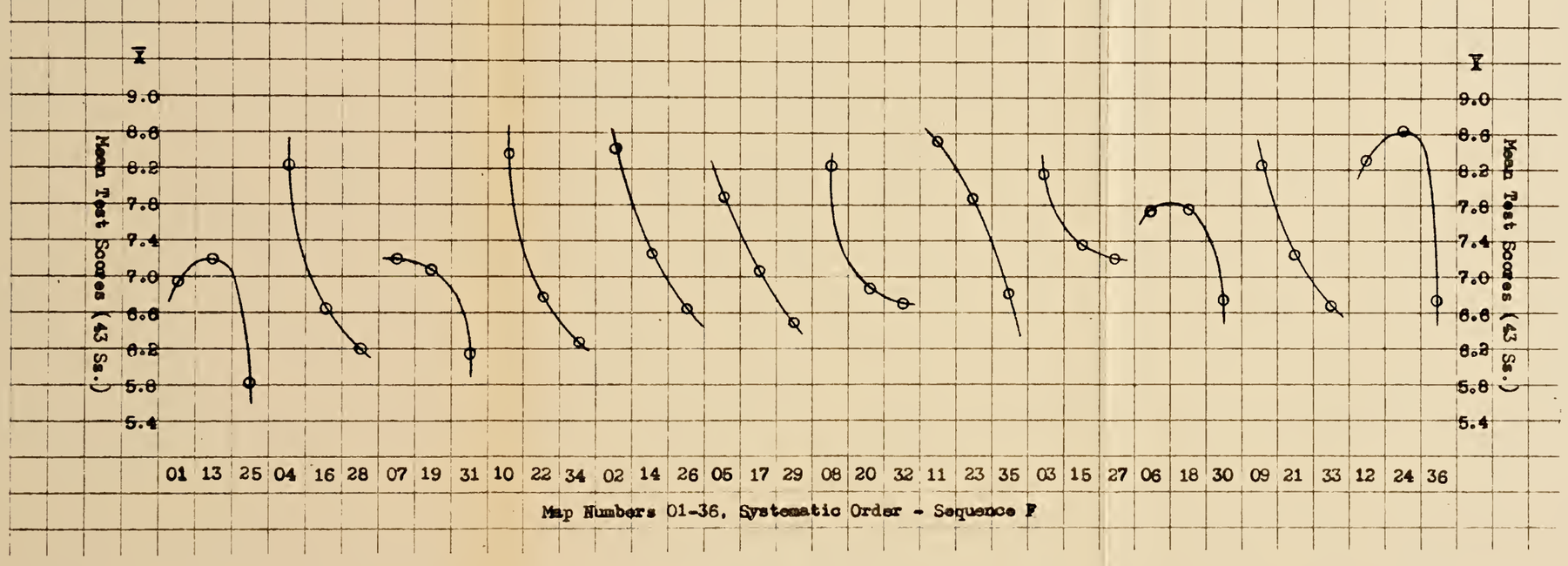


TABLE 44

SMOOTHED-MEAN SCORE VALUES

Smoothed-Mean Values of Mean Test Score Sets on Tables 38-43

Values listed below are averages of triplet and quadruplet sets of data graphed on Tables 38-43. These averages are plotted on the graphs on Tables 45-47.

From 38 - Tables - 39		From 40 - Tables - 41		From 42 - Tables - 43	
A ::::::::::::: B Table 45		C ::::::::::::: D Table 46		E ::::::::::::: F Table 47	
7.86 }	7.70 }	6.67	7.86	7.70	6.67
7.96 }	8.28 } **	7.45	7.29	6.94	7.03
7.91 } *	8.13 }	7.60	6.57	6.13	6.83
8.41 }					7.17
7.29	6.94	7.03	7.96	8.28	7.45
7.05	7.30	7.19	7.05	7.30	7.19
7.09	7.66	7.29	6.49	6.69	7.31
7.77					7.75
6.57	6.13	6.83	7.91	8.13	7.60
6.49	6.69	7.31	7.09	7.66	7.29
6.54	6.85	7.41	6.54	6.85	7.41
6.62					7.90
		7.17	8.41		
		7.75	7.77		
		7.90	6.62		

Smoothed-Mean Values of Above Sets of Smoothed-Mean Values

*, ** Values listed below are averages of above sets.

A ::::::::::::: B Table 45		C ::::::::::::: D Table 46		E ::::::::::::: F Table 47	
8.03 } *	8.03 } **	7.24	7.24	6.92	6.92
7.30	7.30	7.17	7.17	7.42	7.42
6.55	6.55	7.18	7.18	7.55	7.55
		7.60	7.60		

LEGEND - Line Symbols, Tables 44-47:

::::::::::::: - Denotes two sets of above values plotted on one graphic display.

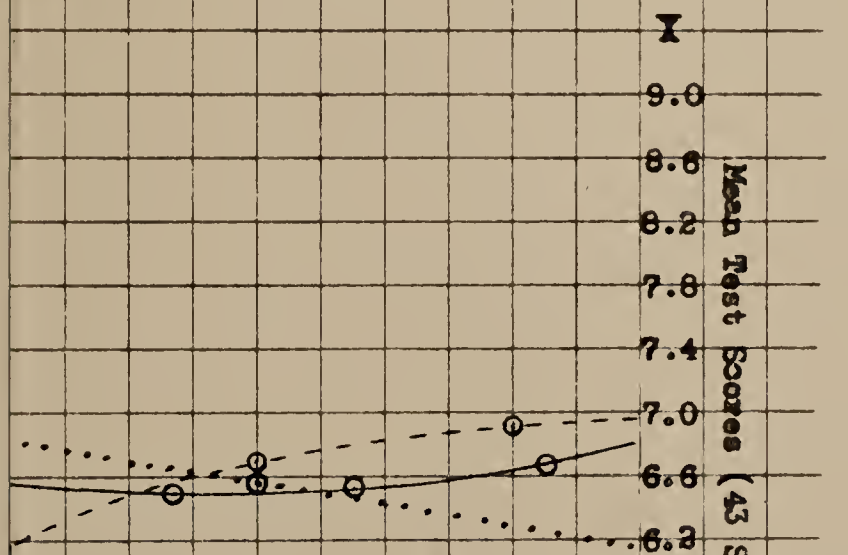
———————— - Graph symbol denoting Background factor cases.

- - - -

FOR

Order & Symbol Codes:

14	06	28	07	17	10	12	34	05	20	A	X
17	34	18	28	10	05	14	07	12	20	B	X
1	2	2	2	3	3	3	4	4	4	A	SK
1	1	2	2	2	2	3	3	3	3	B	SK
3	3	3	3	3	3	3	3	3	3	A/B	K

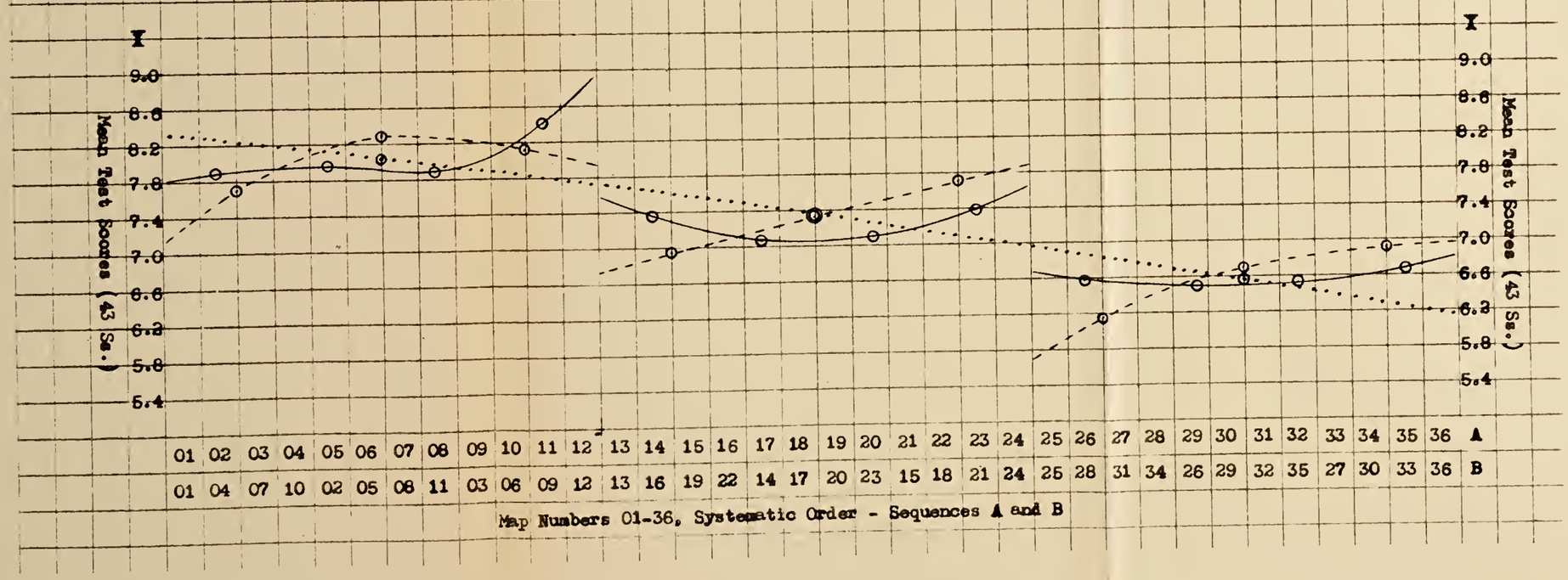


27	28	29	30	31	32	33	34	35	36	A
31	34	26	29	32	35	27	30	33	36	B

TABLE 45

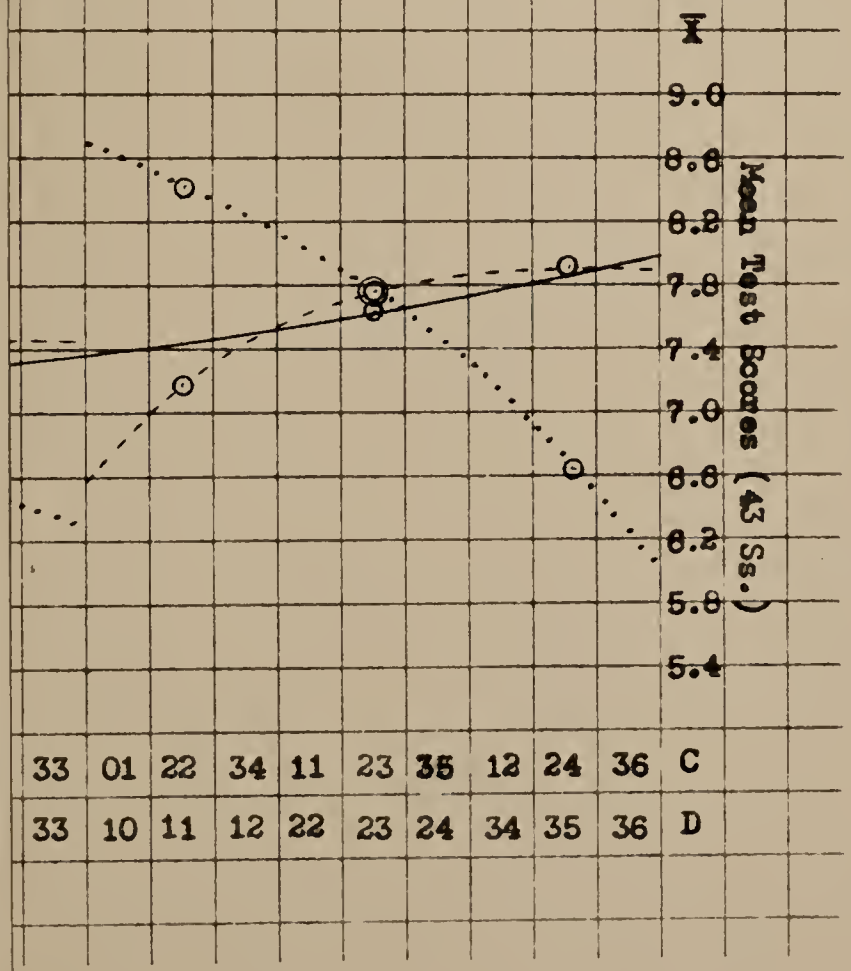
SMOOTHED-MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR BACKGROUND AND LINE-WIDTH EFFECTS ON VIEWING DISTANCE

																																		Order & Symbol Codes:	
Random Test-Order Numbers	15	31	36	09	35	04	24	02	16	32	30	01	33	03	22	21	27	13	25	26	23	11	19	08	29	18	14	06	28	07	17	10	12	34	05	20	A	X
	15	09	24	32	31	35	02	30	36	04	16	01	33	21	25	11	03	27	26	19	22	13	23	08	29	06	17	34	18	28	10	05	14	07	12	20	B	X
Background Cases	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4	A	SK
Line-Width Cases	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3	B	SK
Viewing Distance Cases	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	A/B	K



S FOR

										Order & Symbol Codes:	
12	32	11	34	30	19	35	10	08	20	C	X
12	32	30	01	11	19	08	34	05	20	D	X
3	1	1	1	2	2	2	3	3	3	C	SK
3	1	1	1	2	2	2	3	3	3	D	SK
3	4	4	4	4	4	4	4	4	4	C/D	K

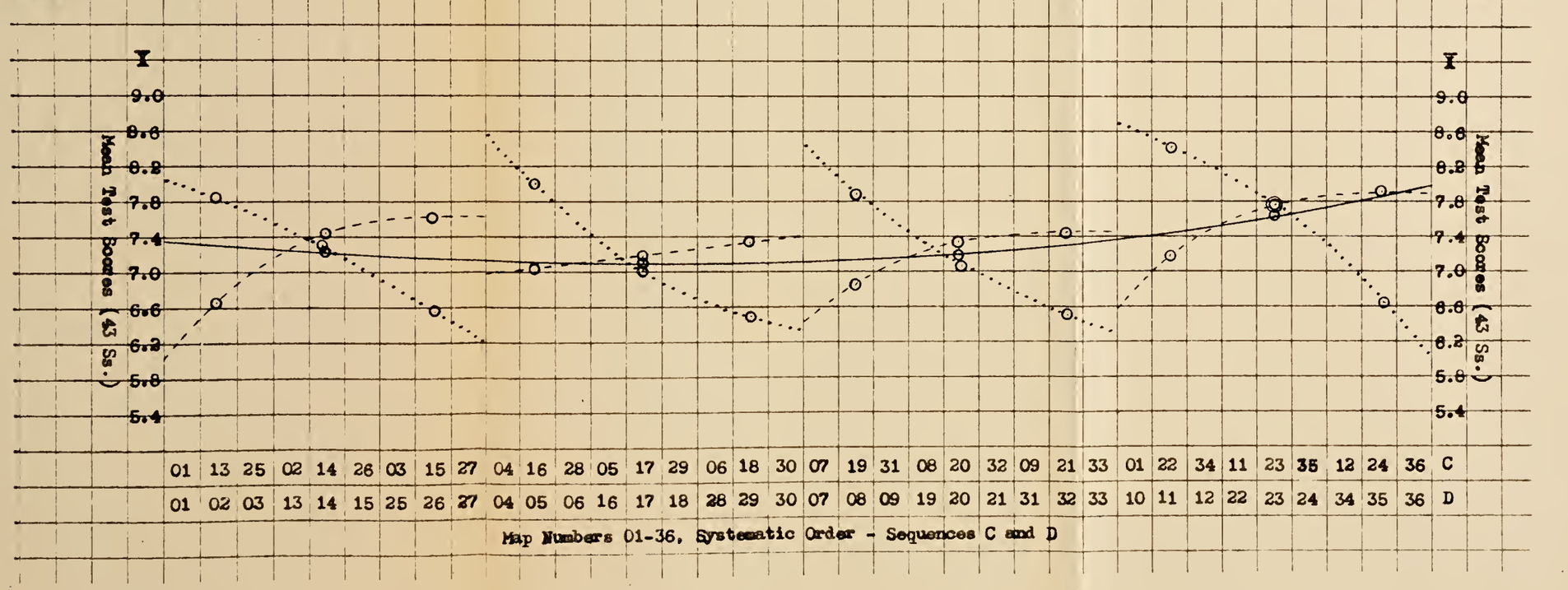


33	01	22	34	11	23	35	12	24	36	C
33	10	11	12	22	23	24	34	35	36	D

TABLE 46

SMOOTHED-MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR LINE-WIDTH AND VIEWING DISTANCE EFFECTS ON BACKGROUND

																																			Order & Symbol Codes:	
Random Test-Order Numbers	15	33	29	31	03	18	36	22	14	09	21	06	35	27	28	04	13	07	24	25	17	02	26	10	16	23	12	32	11	34	30	19	35	10	08	20	C	X
	15	31	36	33	03	22	29	18	14	09	35	04	21	27	13	06	28	07	24	02	16	25	26	23	17	10	12	32	30	01	11	19	08	34	05	20	D	X
Line-Width Cases	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	C	SK
Viewing Distance Cases	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	D	SK
Background Cases	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	C/D	K



OR											
										Order & Symbol Codes:	
16	01	22	13	23	08	14	07	12	20	E	X
14	04	13	07	16	23	12	01	08	20	F	X
1	1	2	2	2	2	3	3	3	3	E	SK
1	2	2	2	3	3	3	4	4	4	F	SK
3	3	3	3	3	3	3	3	3	3	E/F	K
09	12	15	18	21	24	27	30	33	36	E	
27	06	18	30	09	21	33	12	24	36	F	

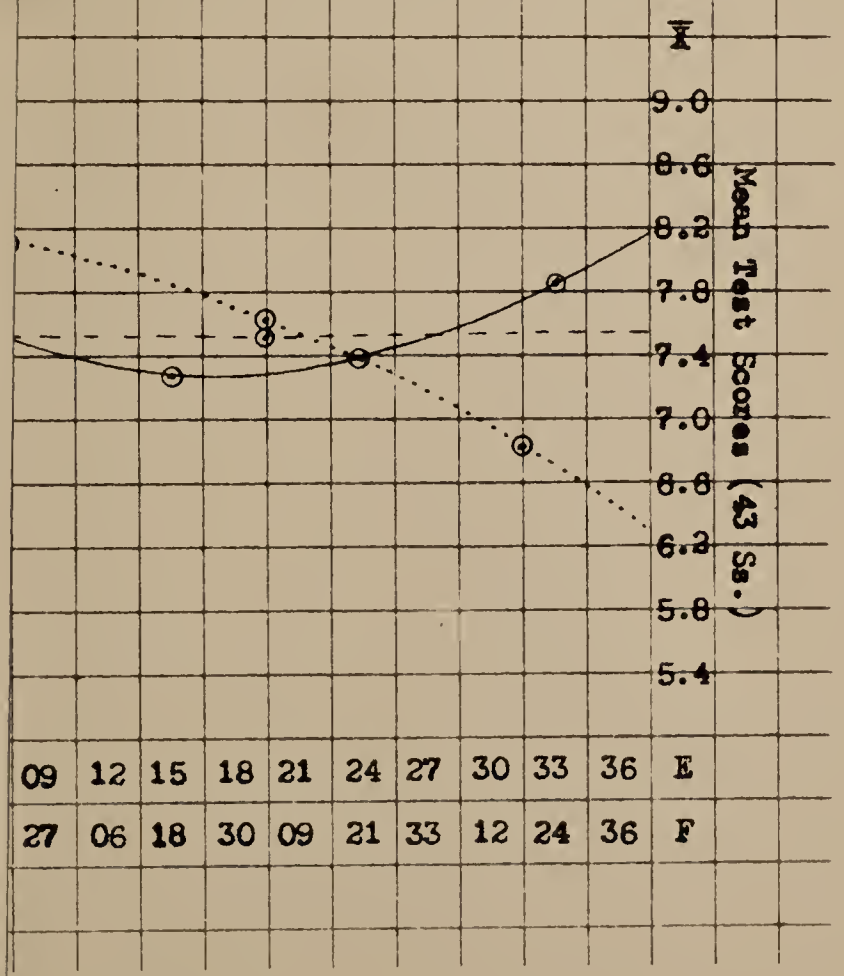
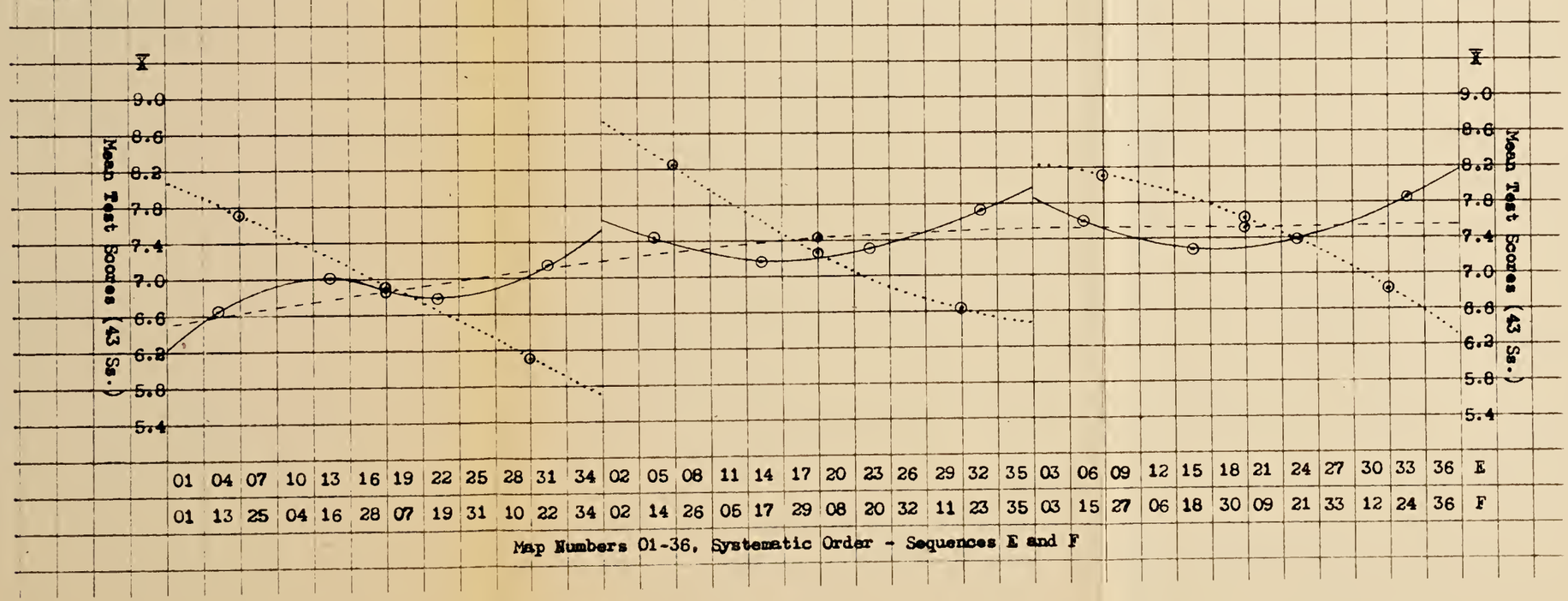


TABLE 47

SMOOTHED-MEAN TEST SCORE DISTRIBUTION - MAP READABILITY TRENDS FOR VIEWING DISTANCE AND BACKGROUND EFFECTS ON LINE-WIDTH

																																	Order & Symbol Codes:	
Random Test-Order Numbers	15	09	24	32	33	21	25	11	29	06	17	34	31	35	02	30	03	27	26	19	18	28	10	05	36	04	16	01	22	13	23	08	14	07	12	20	E	X
	15	33	29	09	21	06	24	25	17	32	11	34	31	03	18	35	27	28	02	26	10	30	19	05	36	22	14	04	13	07	16	23	12	01	08	20	F	X
Viewing Distance Cases	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3	1	1	1	1	2	2	2	2	3	3	3	3	E	SK
Background Cases	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	2	2	2	3	3	3	4	4	4	F	SK
Line-Width Cases	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	E/F	K



Interpretation of Map Test Scores and Trends

Map Rank and Score Summary. Through examination of the Map Rank and Score Summary (Table 37) it is evident that a majority of the first twelve maps with the highest readability ranking[5] have certain common characteristics. The seven inch viewing distance (VD-1) prevails in most cases. Image and background combinations in most instances are either white on a black background (BK 4) or white on a gray background (BK 3 or BK 2), rather than black on a white background (BK 1). Also, for the first twelve maps, the images with heavier line-widths measuring 0.045 inch (LW 3) and 0.030 inch (LW 2) are in the majority. On the other hand, the maps which ranked lower than the first twelve contained images having thinner line widths of 0.015 inch (LW 1) and 0.030 inch (LW 2), and had greater viewing distance specifications of 14 inches (VD 2) and 21 inches (VD 3). Summarizing these statements and overall rank-order observations it appears that, for a majority of the partially seeing subjects tested, the highest ranking (first twelve) maps with white images having heavier line-widths (LW 3, 2), dark backgrounds (BK 4, 3, 2) and viewed at close range (VD 1) have better readability properties than the other maps used in this experiment.

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[5]Map readability is defined as the speed and accuracy with which the test symbols are read and identified. The maps in this experiment were observed and interpreted during two minute time intervals.

The Σ (accumulated) point score range of 121 and $\overline{X}$ (mean) score range of 2.82 (Table 37) indicate a significant amount of variation in visual performance (map readability) on the test maps. This statement must be qualified by noting that these specific point score and mean score ranges fall between extreme test score performance range limits of 250-371 and 5.81-8.63, respectively, which in turn must be further qualified. The point score test performance range limits fall between minimum and maximum point score limits, i.e., for any given map in the test, a maximum of 430 accumulated points (10 points/map/43 subjects) or a minimum of 0 points might have been accrued. Hence, all of the maps were readable to some degree, some better than others, and none of the maps were read perfectly by all of the test subjects. The minimum and maximum mean score limits are between 0 and 10. If the mean score performance range is converted to a percent value, and if this value is interpreted as a percentage of the minimum-maximum (0-10) mean score scale, also expressed as a percentage, it can be seen that a 28.2% difference in mean test score subject performance (map readability) exists between the highest and lowest ranking maps. These rank-order, point score and mean score observations suggest a tentative measure of confirmation of the dissertation hypothesis. In other words, these data suggest that white line symbology printed on a black or gray background are more readable, or as readable, as black printed on a white background.

It is significant to point out that of the maps ranking 1 through 12 (Table 37, page 104), ten have white line symbology with black or gray background. The predominence of maps with black symbology on a white background, rank orders 13.5 through 22, again gives credence to the notion that maps with white symbols on black or gray backgrounds are more readable. The test data indicate that most maps were more readable at the viewing distance of 7 inches (VD 1), although some had a high readability ranking at 14 inches (VD 2). The rank order test evidence regarding line-width, while somewhat mixed, does demonstrate that heavier line widths contribute to higher levels of readability.

Mean Trend Summary. All of the trend lines on Tables 38-43 reflect subject responses from the groups of three simultaneously interacting test factor cases (varied, semi-constant, constant), arranged in trend array sets of three or four test factor cases.[6] The map readability effects of the varied (V) test factor cases upon the other semi-constant (SK) and constant (K) test factor cases are especially revealed by the trend line peaks, low points and amount of

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[6]On Tables 38-43, a group of test factor cases is defined as a vertical row of varied, semi-constant and constant test factor cases for one map. A set of test factor cases is defined as a horizontally arrayed sequence or series of groups of test factor cases for a successive array of three or four maps.

variation. In a few instances, multiple peaks and low points were exhibited along a given trend line. When successively examined, the trend lines also indicated map readability effects of semi-constant and constant arrays of test factor cases. Clusters of three or four trend lines generally coincided with these types of arrays of test factor cases. These clusters appeared at specific levels of mean test score. Some trend lines had inverse or reverse configurations, while others recurred several times on the same graphic array. This repetition (frequency of occurrence) or deviation from the most frequently occurring trend line pattern suggested that certain map sets had similar readability characteristics coinciding with particular arrangements of map test factor cases. The map sets exhibiting the highest mean scores and lowest mean score variances suggested optimal design combinations of map test factor cases. In the following trend line interpretation and summary, all of the mean score values and ranges mentioned will be described as being high, medium or low on the graphic scale, and the reader may easily note particular score values directly from the graphic tables. The mean score values plotted on the graphs may be interpreted as percent values, as in the map rank and score summary.

On Table 38, seven of the trend line peaks coincide with the 0.045 inch heavy line-width (LW 3), suggesting that maps with such heavy line symbols might be more readable than maps with thin or

medium line widths (LW 1, LW2). Also, there is a multiple recurrence (four times) of trend line peaks coinciding with the 0.030 inch medium line-width (LW 2). This observation suggests that some maps with symbols of medium line-width might be more readable than maps with a thin or heavy line-width. In all but one map set on Table 38 (map numbers 04-05-06, inverse line configuration)[7] the trend line peaks coincided with heavy or medium line-widths. Hence the frequency of recurrence of the trend line peaks generally indicate that better map readability is achieved at the 0.045 inch line-width value (LW 3), and in some instances the 0.030 inch line-width value (LW 2) might be more readable or of equivalent readability to the heavier line symbols. Low values of the trend lines were most frequently observed to coincide with the 0.015 inch thin line-width (LW 1).

On Table 38, map set 10-11-12 exhibits the highest mean score, and map set 28-29-30 the lowest mean score.[8] The maps in set 10-11-12 have a black background characteristic (BK 4), a close viewing distance attribute (VD 1), a low range of mean score variance relating to all line-widths (LW 1, 2, 3) and the highest mean score

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[7] "Systematic Order Numbers" are noted throughout this summary. These numbers appear in horizontally arrayed sequences at the bottom of the graphic tables mentioned.

[8] See Table 44 for map set mean scores listed under respective array sequence code letter designations - A, B, C, D, E, F.

values. These observations suggest that, for maps having a black background and viewed at close range, the three line-widths used in this experiment had a negligible effect on map readability. Hence, maps with a black background (BK 4), viewed at close range (VD 1) might be effectively designed using thick, medium or thin white lines (LW 1, 2, 3).

When observed sequentially, the trend lines on Table 38 appear to be grouped in three clusters, each composed of four trend lines, at three levels of mean score. The cluster of trend lines for maps 01-12 has the highest mean scores, and the cluster of trend lines for maps 25-36 has the lowest mean scores. These low and high score clusters of trend lines appear to coincide with the 21 inch far (VD 3) and 7 inch near (VD 1) viewing distances, respectively. Hence, it might be concluded that the maps viewed at close range (VD 1) are more readable than those maps viewed at the greater distances (VD 2, 3) used in this experiment. One exception to this generalization must be noted, i.e., the trend line for map set 22-23-24 has a relatively high mean score level at the 14 inch viewing distance (VD 2). The combination of a black background characteristic (BK 4) and white, heavier line-width characteristics (LW 2, 3) of map-set 22-23-24 appear to contribute to a high level of map readability at a viewing range beyond the 7 inch viewing distance (VD 1).

On Table 39, seven of the trend line peaks coincide with a black map background (BK 4). This high recurrence of trend line peaks suggests that maps with black backgrounds might be more readable than maps with white or gray backgrounds (BK 1, 2, 3), as used in this map test. In two instances trend line peaks coincide with a white map background (BK 1), but the mean scores of these peaks are lower (less readable) than the mean scores for the peaks coinciding with white lines on black or gray backgrounds (BK 2, 3, 4). Low values of the trend lines were most frequently observed to be coincident with a light gray map background (BK 2), however, in two cases coincidence of the low value was a white background (BK 1).

Map set 02-05-08-11 on Table 39 had the highest mean score, and map set 25-28-31-34 had the lowest. The map set having the highest mean score also has a relatively low range of mean score variance relating to all background cases (BK 1, 2, 3, 4), a medium line-width characteristic (LW 2) and a close viewing distance (VD 1). These data suggest that, for maps having a medium line-width and close viewing distance, the backgrounds used in this experiment do not always create significant changes in map readability. Note that the maps in set 03-06-09-12 have similar characteristics to the maps in set 02-05-08-11, except for a heavy line-width characteristic (LW-3). Hence, maps with medium or heavy line-widths (LW 2, 3) and viewed at close range (VD 1) might be effectively designed using

white, gray or black backgrounds (BK 1, 2, 3, 4), although dark gray or black backgrounds would seem to be most desirable.

When observed sequentially, the trend lines on Table 39 appear to be grouped in three clusters, each composed of three trend lines, at three levels of mean score. The cluster of trend lines for map sets 01-04-07-10, 02-05-08-11 and 03-06-09-12 has the highest mean scores, and the cluster of trend lines for map sets 25-28-31-34, 26-29-32-35 and 27-30-33-36 has the lowest mean scores. These high and low score clusters of trend lines appear to coincide with the 7 inch near (VD 1) and 21 inch far (VD 3) viewing distances, respectively. Hence, it might be similarly concluded, as in the analysis of the previous table, that maps in this experiment viewed at close range (VD 1) are more readable than the maps viewed at greater distances (VD 2, 3).

On Table 40, nine of the trend line peaks coincide with the 7 inch viewing distance (VD 1), and three of the peaks coincide with the 14 inch viewing distance (VD 2). The high recurrence of the 7 inch viewing distance peak suggests that maps having this close viewing range characteristic (VD 1) might be more readable than maps with more distant viewing range characteristics (VD 2, 3), as used in this experiment. All low values of the trend lines on Table 40 were observed to coincide with the 21 inch far viewing distance (VD 3).

Map set 12-24-36 on Table 40 exhibits the highest mean score, and map set 01-13-25 the lowest. The map set having the highest mean score also has a low mean score variance relating to the 7 inch close and 14 inch medium range viewing distances (VD 1, 2) and a high variance with respect to the 21 inch far viewing distance (VD 3).[9] Map set 12-24-36 has characteristics of a white, heavy line-width (LW 3) and a black background (BK 4). These observations suggest, that for maps having a white, heavy line-width and black background, the close and medium range viewing distances used in this experiment cause only slight changes in map readability. Hence, maps with a white, heavy line-width (LW 3) and a black background (BK 4) might be most effectively designed for use at close or medium range viewing distance (VD 1, 2).

Sequential observation of the trend lines on Table 40 does not reveal any clear clustering of trend lines, except for the two adjacent trend lines representing map sets 11-23-35 and 12-24-36. All of the trend lines have nearly the same mean score level, except for trend lines for map sets 01-13-25 and 07-19-31 which have the lowest mean scores. Two other map sets having relatively low mean scores are

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[9] This mean score variance pattern is also noticeable for map sets 01-13-25, 06-18-30 and 07-19-31.

sets 04-16-28 and 10-22-34. The trend lines for the low scoring map sets all coincide with the 0.015 inch thin line-width (LW 1) and the white or gray map background characteristics (BK 1, 2, 3). The cluster of two map sets (11-23-35 and 12-24-36) having the highest scores appear to coincide with white, 0.030 inch medium and 0.045 inch heavy line-widths (LW 2, 3) and the black map background (BK 4). In this case it is suggested that maps with white, heavier line-widths (LW 2, 3) and a black background (BK 4) are more readable than maps with a thin line-width (LW 1) and white or gray backgrounds (BK 1, 2, 3) used in this experiment.

Table 41 is an alternate arrangement of Table 38, and therefore the map sets and their corresponding trend lines are identical to those on Table 38, only in different array positions on this table. Map readability and design distinctions suggested by the trend line characteristics on this table are identical to those on Table 38 (see comments for Table 38, pages ~~106~~ 119-121), with one addition. When examined sequentially, the trend lines appear to be arranged in four clusters of three trend lines each, indicating similar distinctions in a slightly different manner. In each of these four clusters, the trend line having the highest mean score coincides with the 7 inch viewing distance characteristic (VD 1), and that with the lowest mean score coincides with the 21 inch viewing distance (VD 3). This observation suggests that most maps viewed at 7 inches (VD 1) are more readable than those

viewed at 14 and 21 inches (VD 2, 3). Also, it appears that line-width and background variations do not greatly affect the readability level of most maps viewed at the 7 inch range (VD 1).

Table 42 is another arrangement of Table 39, and hence the map sets and their corresponding trend lines are identical, except in their array positions. Map readability and design distinctions suggested by the trend line characteristics in this table are identical to those suggested for Table 39 (see comments for Table 39, pages ~~107~~ 122-123) with one addition. When observed sequentially, the trend lines appear to be arranged in three clusters, each composed of three trend lines, indicating similar distinctions in a slightly different manner. In each cluster, the trend line having the highest mean score coincides with the 7 inch viewing distance characteristic (VD 1), and the trend line having the lowest mean score coincides with the 21 inch viewing distance (VD 3). This suggests that maps viewed at 7 inches (VD 1) are more readable than maps viewed at 14 and 21 inches (VD 2, 3). Also, it appears that background and line-width variations do not greatly affect the readability level of most of the maps viewed at the 7 inch range (VD 1).

Table 43 contains a different arrangement of data shown in Table 40, and therefore the map sets and their corresponding trend lines are identical except in array positions. Map readability and design distinctions suggested by these trend line characteristics are

identical to those on Table 40 (see comments for Table 40, pages 123-125). When observed sequentially, there are no clearly distinct clusters of trend lines on Table 43, but there is a marginally detectible increase in the mean score of the map sets corresponding to an increase in the line-width characteristic of the map sets. Trend lines having the highest scores coincide with the 0.045 inch heavy line-width (LW 3), and trend lines having the lowest scores coincide with the 0.015 inch thin line-width (LW 1). Variations in viewing distance seem to affect the individual map sets and their corresponding trend lines only, while variations in background cases do not appear to affect these trends. Hence, these observations suggest that maps with a heavy line-width (LW 3) are more readable than maps with thinner line-widths (LW 1, 2) used in this experiment.

The graphic arrays on Tables 45-47 permit observation and interpretation of trend lines derived from the smoothed-mean values of combined clusters of map sets.[10] These clusters of map sets and their respective trend lines correspond to semi-constant (SK) and constant (K) arrangements of map test factor cases on the tables.

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[10] See Table 44 for smoothed-mean score values, and legend identifying these trend line symbols.

The trend lines corresponding to the semi-constant arrays of map test factor cases (pairs of short trend lines, each defined by three or four points of locus) facilitate detection of suggested optimally readable map design combinations. These peak combinations of map test factor cases are suggested by the points of intersection where two trend lines cross one another on the graphs. Tables 45-47 also contain secondary, smoothed-mean trend lines derived from the smoothed-mean test score values.[11] These trend lines correspond to the constant (K) arrays of map test factor cases (one long line per graph, each line defined by three or four points of locus). General map readability effects of the constant array of map test factor cases are suggested by these trend lines.

On Table 45, a 7 inch near viewing range characteristic (VD-1) is common to the pair of smoothed-mean trend lines (first pair of curves from the left) having the highest smoothed-mean value intersection point. This point of intersection corresponds to a map test factor case combination consisting of a black background (BK 4) and a white 0.045 inch, heavy line-width (LW 3). Hence, maps designed with a white, heavy line-width (LW 3), black background (BK 4) and viewed

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[11] See Table 44 for secondary, smoothed-mean score values, and legend identifying these trend line symbols.

at close range might be more readable than maps having greater viewing distances (VD 2, 3), white or gray backgrounds (BK 1, 2, 3) and thinner line-widths (LW 1, 2), as employed in this experiment. The secondary, smoothed-mean trend line on Table 45 (dotted line) suggests that there is a general decrease in map readability as viewing distance is increased.

On Table 46, a black background (BK 4) is common to the pair of smoothed-mean trend lines (fourth pair from the left) having the highest smoothed-mean value intersection point. This point of intersection corresponds to a map test factor case combination consisting of a white, 0.030 inch medium line-width (LW 2) and a 14 inch viewing range (VD 2). Hence, maps having a medium viewing range (VD 2), a white, medium line-width (LW 2) and a black background (BK 4) might be more readable than maps having white or gray backgrounds (BK 1, 2, 3), white or black, light or heavy line-widths (LW 1, 3) and near or far viewing distances (VD 1, 3), as used in this experiment. The secondary, smoothed-mean trend line on Table 46 (solid line) suggests that there is a general increase in map readability corresponding with both a white and black map background (BK 1, 4). The light gray background case (BK 2) has the lowest score level. Hence, a black map background (BK 4) with white line symbols or the white with black symbols (BK 1) might increase map readability more effectively than the gray background (BK 2, 3) used in this experiment.

On Table 47, a white, heavy line width characteristic (LW 3) is common to the pair of smoothed-mean trend lines (third pair from the left) having the highest smoothed-mean value intersection point. This point corresponds to a map test factor case combination consisting of a 14 inch medium viewing distance (VD 2) and a dark gray background (BK 3). Hence, maps having a dark gray background (BK 3), a medium viewing range characteristic (VD 2) and a heavy line-width (LW 3) might be more readable than maps having thinner line-widths (LW 1, 2), near or far viewing distances (VD 1, 3) and white, light gray or black backgrounds (BK 1, 2, 4). The secondary, smoothed-mean trend line on Table 47 (dashed line) suggests that there is a general increase in map readability in response to a heavier line-width. Thus, a 0.045 inch heavy line-width (LW 3) might tend to increase map readability more effectively than the thin or medium line-widths (LW 1, 2) used in this experiment.

Conclusions

Rank and Mean Trend Interpretations. The interpretation of map test scores and trends has suggested the existence of some significant differences in map readability relating to the individual and combined map test factor cases used in this experiment. Both the map rank and score summary and the mean trend summary indicate that the highest level of map readability corresponds with a white,

heavy line-width (LW 3), black background (BK 4) and close viewing distance (VD 1). This combination of map test factor cases might be construed as representing the optimal suggested design characteristics for maximum map readability. Other combinations of map test factor cases include a medium line-width (LW 2), white and dark gray backgrounds (BK 1, 3) and a medium viewing distance (VD 2) had high scores, but not as frequently.

According to observations of the trend line graphs, Tables 38-43 and 45-47, the effects of the line-width, background and viewing distance factors on map readability may be stated as follows: (1) increases in line-width usually correspond with increases in map readability; (2) white-line symbols on progressively darker map backgrounds, especially black, usually correspond with increases in map readability; and (3) decreases in viewing distance usually result in increases in map readability.

Also, according to observations of these trend graph lines, the effects of line-width, background and viewing distance cases upon each other, in improving map readability, may be stated as follows: (1) all background and viewing distance cases are enhanced by increases in line-width; (2) all line-width and viewing distance cases are enhanced by progressively darker map backgrounds, especially black, although in certain cases a white background with black, heavy lines is almost

equally effective;[12] and (3) all line-width and background cases are enhanced by decreases in viewing distance.

Numeric values and percent values were not mentioned in the mean trend summary since the averaging and smoothing processes as well as the small test population tend to reduce the reliability of such data. However, on inspection of certain map sets such as map numbers 22-23-24 on Table 38, map numbers 15-18-21 on Table 39 and map numbers 10-22-34 on Table 40, differences in map readability ranging between one and two mean score scale units (between 10 and 20 percent difference when expressed as a percentage of the 0-10 mean score scale) are indicated by the spread of the trend lines. This spread (percentage difference) is similar to that achieved in several other graphic perception experiments involving combinations of variables similar to those used in this experiment.[13]

Statistical Tests. Seeking further confirmation of the conclusions derived through the analysis of the rank and mean trend data, several additional statistical tests were performed. A difference-of-means test was done to determine whether certain test maps with

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[12] The two ends of the tonal spectrum, black and white, each produce increases in contrast between background and images (map symbols) which in turn seems to enhance the line-width and viewing distance cases. The term enhance is taken to mean the extended usefulness of a test factor case in terms of medium to high mean test score level.

[13] Refer to studies cited in footnote 20, Ch. I: Uhlaner, J.F. (1941); Berger, C. (1944); Case, H.W., et.al. (1952); Allen, T.M. and Straub, A.L. (1955); Karmeier, D.F., et. al. (1960); and Herrington, C.G. (1960).

different designs had significant differences in readability.[14] A multiple regression analysis of all mean test response data was performed in order to determine the relative importance of the map test factor cases on map readability (test score).[15] The results of these statistical tests are shown on Tables 48 and 49.

On Table 48, the first three comparisons between background effect on mean score, computations (1), (2) and (3), indicate that, for the maps tested, those having a black background characteristic (BK 4) where associated with mean test scores that were significantly higher (confidence levels of 95 to 90%) than for maps having light gray, dark gray and white backgrounds (BK 2, 3, 1, respectively). The comparison tests, computations (1) and (2), also demonstrate that, for the maps tested, those having light and dark gray backgrounds (BK 2, 3) did not have significantly different test scores. Similarly, test computation (1) points out, for the maps tested, that the test scores are not very different for the maps having either a black or white background (BK 4, 1), although those maps having a black background (BK 4) have slightly superior scores. Computation (4) indicates, for

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[14] Hubert M. Blalock, Social Statistics, New York: McGraw-Hill Book Co., Inc. (1960), pp. 170-176. Maps particularly relavent to the hypothesis were selected to be tested.

[15] Ibid., pp. 326-329, 337-343; W. J. Dixon, Ed., BMD Biomedical Computer Programs, BMDO3R Multiple Regression with Case Combinations, Los Angeles: Health Sciences Computing Facility, Dept. of Preventative Medicine and Public Health, School of Medicine, U.C.L.A. (Sept., 1965), pp. 258-275, Computer Program BMD03R version of May 2, 1966 was employed in the regression analysis.

TABLE 48

TESTS OF SIGNIFICANCE-OF-DIFFERENCE IN SELECTED MEAN SCORES

(1) Background 4 and Background 2:

$\bar{x}_{B4} = 7.607$, $\bar{x}_{B2} = 7.173$; $n^* = 387$;

$\bar{x}_{B4} - \bar{x}_{B2} = 0.434$; $S_{(\bar{x}_{B4} - \bar{x}_{B2})} = 0.195$; $z = 2.226$;

Significant at 95% Confidence Level.

(2) Background 4 and Background 3:

$\bar{x}_{B4} = 7.607$, $\bar{x}_{B3} = 7.186$; $n = 387$;

$\bar{x}_{B4} - \bar{x}_{B3} = 0.421$; $S_{(\bar{x}_{B4} - \bar{x}_{B3})} = 0.192$; $z = 2.193$;

Significant at 95% Confidence Level.

(3) Background 4 and Background 1:

$\bar{x}_{B4} = 7.607$, $\bar{x}_{B1} = 7.243$; $n = 387$

$\bar{x}_{B4} - \bar{x}_{B1} = 0.364$; $S_{(\bar{x}_{B4} - \bar{x}_{B1})} = 0.200$; $z = 1.820$;

Significant at 90% Confidence Level.

(4) Background 4 and Viewing Distance 2 VS Background 1 and Viewing Distance 1:

$\bar{x}_{B4D2} = 7.775$, $\bar{x}_{B1D1} = 7.860$; $n = 129$;

$\bar{x}_{B1D1} - \bar{x}_{B4D2} = 0.085$; $S_{(\bar{x}_{B4D2} - \bar{x}_{B1D1})} = 0.310$; $z = 0.274$;

Not Significant.

(5) Background 4 and Line-Width 2 VS Background 1 and Line-Width 3:

$\bar{x}_{B4W2} = 7.751$, $\bar{x}_{B1W3} = 7.605$; $n = 129$;

Not significant. (Estimated by comparison with data in (4) above.)

* Value of n refers to each case.

the maps tested, that there is no significant difference in the mean scores of the maps with a black background (BK 4) and a medium viewing distance (VD 2) as compared with the mean scores of maps with a white background (BK 1) and a close viewing distance (VD 1). Although these maps with different design characteristics seem to have equivalent readability, the maps with a black background (BK 4) have a definite viewing distance advantage. Likewise, computation (5) denotes, for the maps tested, that there is no significant difference in the mean scores of the maps with a black background (BK 4) and a medium line-width (LW 2) as compared with the mean scores of maps with a white background (BK 1) and a thick line-width (LW 3). Again, these maps with different design characteristics seem to have equivalent readability, but the maps with a black background have a definite line-width advantage. Comparison of the mean scores in computation (5) indicates higher scores for maps with a black background (BK 4).

Data from the regression test (see Table 49) suggest that all map test factor characteristics had significant effects on map readability (mean test scores). These results indicate that mean test scores strongly decrease with an increase in viewing distance. Also, these data point out that mean test scores increase with an increase in background contrast as well as an increase in the line-width of map symbology. The regression coefficients indicate probable relative rates of increase or decrease in mean test score as test factor cases

TABLE 49

REGRESSION OF MEAN SCORES ON MAP TEST FACTORS

Test Factors (Variables) -including all cases-	Partial Correlation Coefficient	Regression Coefficient*
Viewing Distance (see Table 45)	-0.873	-0.74
Background** (see Table 46)	0.411	0.13
Line-Width (see Table 47)	0.602	0.31

$r^2 = 0.799$

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*Amount by which mean test score changes (on the average) with a unit increase or decrease in test factor case value, e.g., as Line-Width increases from 0.015 inches (LW 1) to 0.030 inches (LW 2), the mean test score is expected to increase by a rate of 0.31.

**To facilitate machine processing of this regression computation, the Background cases have been reordered (BK 2, 3, 1, 4), so as to place them in actual mean score sequence (note value levels on Tables 44 and 46).

are changed in unit value (see footnote, Table 49). Coefficients for the background variable are rather low. Perhaps, if true perceptual values of background could be measured in a linear fashion as the dimensions for viewing distance and line-width, then such measures could have been appropriately selected for use in this experiment. Selected linear measurements of background data would be more compatible with the other measurements used, resulting in possible increases in the values of the background coefficients.

The preceding rank and trend interpretations and statistical tests of the map test scores suggest a positive measure of confirmation of the dissertation hypothesis: (A) for some groups of partially seeing students, maps with white line symbology on black or dark gray backgrounds are more readable at greater viewing distances than are maps with identical black line symbology printed on a white background; (B) on maps designed for some groups of partially seeing students, a certain range of line-widths of white symbols drawn on dark backgrounds can be seen further and are more readable than equivalent line-widths of black symbols on light backgrounds; and (C) on maps designed for some groups of partially seeing students, line-widths for white symbols on dark backgrounds may be thinner than line-widths for black symbols on light backgrounds.

CHAPTER IV

CONCLUSIONS

This study was initiated to develop a method of acquiring significant and useful knowledge about the more effective design of maps needed by partially seeing students. The effect of irradiation, the basis for the hypothesis tested in this study, does produce a measurable increase in map readability which is demonstrated by the test responses and their analysis. Those test maps, designed to create the illusion of magnification of map symbols (irradiation), which contained white line symbology on a dark gray or black background enabled subjects to carry through their assigned task with higher over-all accuracy than was achieved utilizing any of the other alternate map designs used in this experiment. It was also clear that it might be possible to use thinner line symbols, in such a design format, and greater viewing distances without significant decrease in subject response accuracy (as suggested by the difference-of-means test). The design, production, testing and analysis system employed in this study is a new development in the field of experimental cartography. This system has effectively demonstrated that new map design characteristics can be developed and tested in a controlled manner using a psychophysical investigative approach.

Validity of Test Design, Production System and Analytical Techniques

The map test design employed in this study has provided a means for the acquisition of a range of subject response differences to a selective array of map design stimuli under prescribed controls for the subjects, test environment and test maps. Once the test design was formulated and the test materials assembled, the system of testing itself was easy to execute, well received by the subjects, and amenable to fast recovery of the response data recorded on the answer sheets. Thus it might be concluded that the map test has performed its intended tasks, and that its design may be a valid one.

The multiple-use, photomechanical system employed in the production of the map test was of a highly technical nature and costly in terms of materials, equipment and labor. Still, there are no other known production approaches or methods available which could have been used to create maps with the design characteristics and tolerances required for this study. The different maps made for the map test produced a range of low to high readability levels (test scores) for the subjects. This was exactly the desired response reaction.

Selected, descriptive statistical analytical techniques were effectively utilized in this study to interpret differences in the map test scores. Rank and mean graphic trend interpretations were made as well as tests of difference-of -means and regression analysis.

The graphic method was especially useful in the detection of significant combinations of map characteristics and the other tests helped to confirm the graphic interpretations. The analytical techniques provided enough significant interpretations to formulate tentative conclusions about the map design characteristics investigated.

Further extensions of this study, and the design of other methods of psychophysical map testing are needed before a more comprehensive evaluation of the validity of this test design, production and analysis system can be made.

Findings of Test Data Analysis and Resultant Design Recommendations

The most readable map design characteristics suggested in the preceding analysis were white line symbols of heavy line-width (0.045 inch/1.143 millimeters), a grayish-black background (Munsell Number 2/) and a close viewing distance (7 inches/17.78 centimeters). Some test maps with white line symbols of medium and thin line-widths (0.030 inch/0.762 millimeter and 0.015 inch/0.381 millimeter, respectively), black and dark gray backgrounds (Munsell Numbers 2/ and 4/, respectively), and close and medium viewing distances (7 inches/17.78 centimeters and 14 inches/35.56 centimeters, respectively), also attained relatively high levels of readability. Maps with black line symbols of heavy and medium line-widths (specified above), a white background (Munsell Number 9/), and a close viewing

distance (specified above) had relatively high readability levels too. These data suggest possible ranges of map design specifications for line-width, background and viewing distance: line-widths - from 0.045 to 0.015 inch (1.143 to 0.381 millimeters), backgrounds - tonal values of black, dark gray and white (Munsell Numbers 1/, 4/ and 9/), and viewing distances - from 7 to 14 inches (17.78 to 35.56 centimeters). Selection of combinations of design specifications within these range limits might therefore result in the making of readable maps for partially seeing students. It would be desirable to select the thinnest possible line-width and a black background in order to reduce the amount of symbol clutter and ambient light reflection, respectively. Selection of the longest possible viewing distance would permit the broadest viewing scan. Selection of medium to medium dark gray map backgrounds (Munsell Numbers 5/ and 4/) would probably provide about as high a readability level as a black background, plus the advantage of being able to use both white and black contrasting symbology. Thin line-widths less than 0.015 inch (0.381 millimeter), light gray backgrounds (Munsell Numbers 7/ and 8/) and viewing distances exceeding 14 inches are not recommended as specifications for maps for partially seeing students.

Extension of Test as to Numbers of Subjects and Types of Variables

Further extensions of this study should be attempted, using the map test to gain a larger sampling of subject responses, possibly up to several hundred. Then these responses could be analyzed according to selected subject diagnosis (group etiology), and tests of statistical significance could be applied to these data. Since there are different diagnostic types of partially seeing persons having varied residual vision capabilities, it follows that they ought to be identified and classified in terms of their particular cartographic design characteristic limits and ranges, rather than assuming a general set of design limits and ranges. It may be possible, eventually, to formulate statistically valid general design characteristics derived from several different sets of limits and ranges.

Another possible extension of the map test would be to change thetypes of variables (map test symbol design as well as viewing characteristics) to be investigated. The kinds of variables investigated in this study (line-width, background and viewing distance) were selected because they were thought to be most revealing with respect to the effects of the irradiation illusion in the context of a simple outline map to be used by partially seeing students. Other viewing characteristics warranting investigation include map orientation, object and room lighting levels and scanning time. Map symbol

characteristics needing basic research include configurations, dimensions, angular orientations, tones and colors. Point symbols of a geometric and pictorial nature, area symbols and notational symbols all should be analyzed in map context with respect to the readability of their design characteristics. It may also be possible to check the effective readability or discrimination of tactual map symbology. Perhaps this test could even be modified to test tactual versions of the line symbols utilized in the test maps.

Addition of Variables and Analytical Capabilities Through Machine Operations

It might be possible to extend the design and analytical capabilities of the map test by adding more variables (map test characteristics and variations thereof). This would be desirable because it is obvious that there are far more than three dominant variables simultaneously affecting map readability. Manual handling of the data record and analytical matricies used in this study would be difficult, indeed, if more than three variables (and variations thereof) were incorporated. Therefore, it is suggested that if this map test is extended by increasing the number of variables and/or the number of variations of these variables, as well as including other statistical tests, then machine data processing and analyzing techniques of operation should be applied. This might necessitate the adaptation

to, or modification of, already existing electronic accounting machine procedures for the test score tally sheet records, the creation of a special, multiple-factor graphic trend array program, and the inclusion of a multiple-factor correlation program for comprehensive analysis of large numbers of map design characteristics versus different types of subjects and responses.

Recommendations for Map Production

A multiple-use, photomechanical approach is recommended for the production of new maps for partially seeing students. Such an approach would tend to increase production flexibility and reduce costs by allowing one or several base map(s) to be used for many different purposes (including periodic modifications and revisions), as well as permitting the optional use of several different modes of reproduction such as Ozalid or offset lithographic printing for short or long runs, respectively. Map cells for overhead projection[1] also could be easily produced from the same master positives and negatives used in preparing master plates for common reproduction processes. The creation of dual modality maps having large visual symbols and

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[1]It was discovered during preliminary research for this study that partially seeing students could scan and read projected maps at greater viewing distances and over broader scanning areas than possible with desk outline maps. These effects may be due in part to greater image magnifications and greater image-to-background contrasts produced by optical projection onto a large screen.

raised tactual symbols is still another possibility.[2] Both blind and partially seeing students frequently are trained together in sight-saving classrooms for the visually handicapped. Hence, both types of students could simultaneously use these maps, and the instructor would be aided by the visual symbols. By using such maps, some partially seeing students who are gradually losing their residual vision, perhaps would be able to make the transition from visual to tactual maps and graphics more easily.

The use of scribing tools in the production of master map base reproduction media is highly recommended for several basic reasons. First, symbols of uniform and precise dimension can be scribed to exact specifications for particular needs. A map to be used at a specific viewing distance, for example, can be scribed to the particular line-width dimension suitable for that specified viewing distance. A second advantage to scribing is the reduction in map reproduction costs made possible by the elimination of one photographic stage, in

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[2]A raised, tactual image can be created from the visible map symbology by printing these images with a special adhesive ink which is dusted with heat-sensitive powder and then thermally exposed. The heat source causes the powder on the images to raise above and affix to the page surface, producing tactual images. This mode of reproduction is known as the Verkitype process. The master reproduction media also could be used in printing visible map images on thermoplastic sheets used in making raised relief tactual images by the Thermoform process. Map molds for this process might be made by indirect use of reproduction masters in conjunction with an acid etching process. The visual map image could be incorporated by preprinting on the flat plastic sheet before forming over the mold.

most cases. By applying a multiple-use production approach and multiple-exposure photographic techniques, the scribing process can be used to facilitate the production of many different kinds of maps or varied and successive versions of the same map. Scribing is also an invaluable tool when it comes to the precision production of symbols on maps, as well as other graphics, to be employed in psychophysical experiments such as the one in this study.

Other Cartographic Uses of the Irradiation Effect

Besides its utility in the construction of maps for partially seeing students, the irradiation effect is or would be advantageous in several other applications in which white symbols are printed on a dark background. Image enhancement can be accomplished by using white outlines adjacent to map symbols printed on darker tonal values or on colored backgrounds. Special radar, infra-red and strategic military maps are designed using white symbols on a dark background or else made using a white edge enhancement surrounding selected symbols in order to make them stand out. The three-dimensional appearance of images achieved through the use of tonal contrasts is somewhat analogous to the visual relief effect observed from adjacent images printed in "warm and cool colors". However, the illusion of image relief from a plane surface may also be related to the irradiation effect, since map symbols may appear to "stand out" when they

are printed in white on a dark background. Realistic terrain maps have been designed with "illuminated contour lines." In this case, selected segments or ordinary black contour lines are printed in white, which imparts an enhanced, three-dimensional visual quality to the contour lines. Maps and map display panels utilized in darkened environments frequently are designed with white symbology against a dark or subdued tonal background. Transmitted or projected rather than reflected light is employed to illuminate the white (and black) map symbology on automated display panels and cathode ray tube displays. Maps used for night navigation also have been produced with white symbols against a dark background, and in a few cases map symbols have been printed with florescent or phosphorescent inks which clearly stand out against a dark background, as well as in a darkened environment. Human factors engineers, who design such maps and map display systems, have applied the notion of irradiance for many years in the development and production of graphics used in low-illumination environments. The enhancement effect of irradiance also can be applied in the design of certain types of topical or thematic maps. For example, star maps ordinarily are printed with white images on a dark background to simulate real conditions of observation. Road maps for night travel might be made in the same manner. In other special applications, white symbology on a dark background might be useful whenever phenomena of two or more major categories

are represented on one map, such as land-water, surface-subsurface, day-night, cold-hot and low value-high value items.

Comments

The recommendations and suggestions presented in this chapter, together with the background material, information on test design, map production and analytical procedures, and summary of map test results provide a new tentative basis for the design, production and further development of maps for partially seeing students. If the new ideas on map design prove to be visually advantageous to partially seeing persons, then there may also be benefits for the development of special maps and graphics for normally seeing individuals. In the fields of special and general education, books and charts as well as maps with white printing on a dark background might be designed and tested. In experimental psychology, the map test design and analytical procedures of this study might be adapted to facilitate figure-background perception research. This study was deliberately written in a very detailed fashion, including rationale, qualifications, definitions, specifications, examples and suggestions, so that the work could be duplicated and used in other related research. It is hoped that this study might serve as a prototype and contain useful data and conclusions for further investigations into the nature of map and graphic design.

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APPENDIX OF EQUIPMENT AND MATERIALS

Drafting and Scribing Tools and Materials

Rapidograph Drafting Pens, sizes 00, 0, 1, 2, 3; Keuffel & Esser Co., New York, N. Y.; for drafting map compilations and for general drafting operations.

Albanene Prepared Tracing Paper, No. 10-7155, cut to 12 in. by 17 in. (30.48 cm. by 43.18 cm.) sheets; Keuffel & Esser Co., New York, N. Y.; for map compilations.

Stainless Steel Straightedge, No. 2900-48, 48in. (120.92 cm.) length, $2\frac{1}{2}$ in. (6.35 cm.) width, beveled edge; Theo. Alteneder & Sons, Philadelphia, Pa.; for compilation, drafting and scribing operations.

Stainless Steel T-Square,No. 2890-42, 42 in. (106.68 cm.) length, fixed head; Theo. Alteneder & Sons, Philadelphia Pa.; for compilation drafting and scribing operations.

Stainless Steel Triangles, Nos. 2936-18 and 2938-18, solid center with lifting knob, 18 in. (45.72 cm.) length, beveled edge, 30-60-90 degrees and 45-45-90 degrees; Theo. Alteneder & Sons, Philadelphia, Pa.; for compilation, drafting and scribing operations.

Tracing (Light) Table, No. 165, 24 in. by 36 in. (60.96 cm. by 91.44 cm.) surface; Hamilton Mfg. Co., Two Rivers, Wis.; for tracing operations and for photographic film correction and editing.

K & E Stabilene Straight Line Graver Tool, with optic, No. 56-0148; Keuffel & Esser Co., New York, N.Y.; for scribing-engraving straight line images.

Swivel Uni-Graver Tool, with optic and lock, No. 102-2; Universal Instrument Co., Brentwood, Md.; for scribing-engraving curved line images.

K & E Stabilene Graver Blades, chisel type, No. 56-0204/0.060 in. ground to 0.045 in. (1.143 mm.) width, No. 56-0196/0.030 in. (0.762 mm.) width, and No. 56-0188/0.014 in. beveled to 0.015 in. (0.381 mm.) width; Keuffel & Esser Co., New York, N. Y.; for scribing tools.

K & E Stabilene Film, Transparent Scribe Coat, Rust Color Coating, dimensionally stable, base thickness 0.0075 in. (0.192 mm.), No. 44-3307/OLD NR 133H, roll stock cut to 12 in. by 17 in. (30.48 cm. by 43.18 cm.) and 12 in. by 14 in. (30.48 cm. by 35.56 cm.) sheets; Keuffel & Esser Co., New York, N.Y.; for producing scribecoat negatives.

K & E Stabilene Scribe Coat Touch-Up Fluid, Rust Color, No. 58-2108/OLD TR 3056; Keuffel & Esser Co., New York, N.Y.; for opaque touch-up correction on Scribe Coat negatives.

K & E Stabilene Scribe Coat Touch-Up Thinner, No. 58-2187/OLD 3057E Keuffel & Esser Co., New York, N.Y.; for thinning Scribe Coat Touch-Up Fluid.

Curve-Line Symbolic Drafting Tape, No. 6221T; Chart-Pak, Inc., Leads, Mass.; for construction of map boundary symbol on Scribe Coat negatives.

Cronar Clear Base Polyster Graphic Arts Film, transparent, dimensionally stable, base thickness 0.004 in. (0.102 mm.), No. C-41, roll stock cut to 11 in. by 14 in. (27.94 cm. by 35.56 cm.) sheets; E. I. Du Pont De Nemours & Co., Inc. Wilmington, Del.; for arrow symbol map array film positive compilations.

Best Test Brand Rubber Cement; Union Rubber and Asbestos Co., Trenton, N.J.; for affixing cut out film arrow images to arrow symbol map array film positive compilations.

Precision Measuring Instruments

Steel Ruler, 49 in. (10ths and 100ths subdivisions) and 126 cm. (mm. and $\frac{1}{2}$ mm. subdivisions), machine etched; Theo. Alteneder & Sons, Philadelphia, Pa.; for large dimensional measurements.

Craftsman, Stainless Steel Rule, 6 in. (10ths and 100ths subdivisions), machine etched, No. 9-4015; Sears, Roebuck and Co., Chicago, Ill.; for small dimensional measurements.

Micro-Mike Microscope, 20 Power, with 0.160 in. graticule (0.002 in. subdivisions), No. 1354; Du Maurier Co., Microscope Division, Elmira, N. Y.; for checking line-widths of scribed map line symbols.

Colight Optical Comparator, 35 power, dual image, illuminated, Model 935; Colight, Inc., Minneapolis, Minn.; for visual quality control comparative checks of map base gray tonal backgrounds.

Kodak Gray Scale, Series V; Eastman Kodak Co., Rochester, N.Y.; for checking tonal values on intermediate film positive and negative test maps.

Munsell Gray Scales; Color Notation Folio, Neutral Value Chips, Munsell Color Co., Baltimore, Md., and Rock Color Chart (1963), Value Chips and Names, The Geological Society of America, New York, N.Y.; for checking and naming tonal values of test map backgrounds.

Photographic Equipment and Materials

Photographic Contact Printing Vacuum Frame, $21\frac{1}{2}$ in. by $25\frac{1}{2}$ in. (54.61 cm. by 64.77 cm.) bed; The Douthitt Corp., Detroit, Mich., for photographic contact printing operations.

Tri-Level Point Source Light Unit; K & M Mfg. Co., Chicago, Ill.; for photographic contact printing operations.

Time-O-Lite Industrial Electronic Timers, Model M-59 (0-1 min. range) and Model P-59-3M (0-3 min. range); Industrial Timer Corp. Parsippany, N.J.; for photographic contact printing, copy camera and film developing operations.

Kodak Photographic Film Ortho Type 3, Estar Base, dimensionally stable base thickness 0.004 in. (0.089 mm.), 14 in. by 17 in. (35.56 cm. by 43.18 cm.) and 11 in. by 14 in. (27.94 cm. by 35.56 cm.) sheets; Eastman Kodak Co., Rochester, N.Y.; for production of intermediate and final film positives and negatives.

Kodalith Liquid Developer, Solutions "A" and "B"; Eastman Kodak Co., Rochester, N.Y.; for developing intermediate and final film positives and negatives.

Kodak Rapid Fixer; Eastman Kodak Co., Rochester, N.Y.; for fixing permanent images on intermediate and final film positives and negatives.

Flat-Tone Contact Screens, dot structure, 133 lines per inch, 65% negative density/35% printing density screen for producing maps with dark gray background, and 45% negative density/55% printing density screen for producing maps with light gray background, screen size 14 in. by 17 in. (35.56 cm. by 43.18 cm.); made from master Caprock screens - produced by controlled camera exposure through Caprock gray contact half-tone screens; Caprock Developments, Inc. Morris Plains, N.J.

Register Pins, Stainless Steel, 0.250 in. (5.58 mm.) pin diameter; Chesley F. Carlson Co., Minneapolis, Minn.; for registering map image and film positions during photographic double and triple exposure contact printing operations.

Scotch Brand Lithographers Tape, red, 3/8 in. (9.5 mm.) width, No. 616; Minnesota Mining and Manufacturing Co., St. Paul, Minn.; for photographic tape registration and masking operations.

Robertson Photomechanix Copy Camera, Model 320 V; Robertson Photomechanix, Chicago, Ill.; used in production of special dissertation illustrations.

Map Test Control Apparatus

Robertson Photomechanix Electronic Photo-Timer, Model IT-1 (0-3 min. range), including red light off-on indicator; Robertson Photomechanix, Chicago, Ill.; for timing map testing intervals.

Light Exposure Meter, Model PR-1; General Electric Co., Bridgeport Conn.; for measuring illumination levels in classrooms used for map testing.

Spacing Sticks, 1/4 in. (5.63 mm.) diameter hardwood rods, cut to 7 in. (17.78 cm.), 14 in. (35.56 cm.) and 21 in. (53.34 cm.) lengths, color coded red, gold and green, respectively, and tipped with non-slip, stainless, vinyl end-covers; used as map test spacing apparatus to maintain subject-object viewing distance and perpendicular orientation.

Sumark Plastiglide Vinyl Tiny Tips, 1/4 in. (5.63 mm.) inside diameter; Keystone Brass and Rubber Co., Inc., Hatboro, Pa.; used as end protectors and stainless friction devices on spacing sticks.

Kress Enamel, quick dry, low odor, Red - No. 23031 and Green - No. 23040; S. H. Kress and Co., New York, N.Y.; for color coding 7-inch and 21-inch spacing sticks.

Super Quality Gold Paint; Star Bronze Co., Alliance, Ohio; for color coding 14-inch spacing sticks.

Dennison Star Symbols, 7/16 in. (9.85 mm.) size, gummed, Red - No. 54-042, Gold - No. 54-022 and Green - No. 54-062; Dennison Manufacturing Co., Chicago, Ill.; for coding map test pages with respect to viewing distance spacing apparatus.

Crystal Bay Transparent Pressure Sensitive Tape, $\frac{1}{2}$ in. (12.7 mm.) width, No. 590; Minnesota Mining and Manufacturing Co., St. Paul, Minn.; used as protective film covering colored star symbols on map test pages.

Answer Sheet Forms

Answer Sheet Forms, 5.5 in. by 11.0 in. (13.97 cm. by 27.94 cm.) sheet size, $\frac{1}{4}$ in. (5.63 mm.) large-print lettering, Ozalid printing process; attached to righthand edge of all map test pages - attachment by underlapping with map page and taping.

Scotch Magic Transparent Tape, 1 in. (25.4 mm.) width, No. 810; Minnesota Mining and Manufacturing Co., St. Paul, Minn.; for Fastening answer sheet forms to map test pages (field-test booklets only).

Scotch Double Coated Pressure Sensitive Tape, $\frac{1}{2}$ in. (12.7 mm.) width, No. 665; for fastening answer sheet forms to map test pages (hard-bound sample editions only).

Booklet Page, Binding and Cover Materials

Technifax Ozalid Card Stock, white-non gloss finish, 53 pound weight, No. 15 XX, 11 in. by 17 in. (27.94 cm. by 43.18 cm.) sheets trimmed to 11 in. by 15.75 in. (27.94 cm. by 40.01 cm.) page size, machine exposure speeds from 18 to 25 in./sec.; Technifax Corp., Holyoke, Mass.; for map page base material.

Ideal book and Key Rings, 1 1/8 in. (28.58 mm.) inside diameter, No. 1-100; Henry T. Adams Manufacturing Co., Boston, Mass.; for fastening 3-hole punched map test booklet pages and booklet covers in a loose-leaf fashion (field test editions only).

Cardboard Booklet Covers, gray-rough finish, 150 pound weight, cover size 12 in. by 20.5 in. (30.48 cm. by 53.07 cm.); protective covers for loose-leaf editions of map test booklet used for field testing.

VITA

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